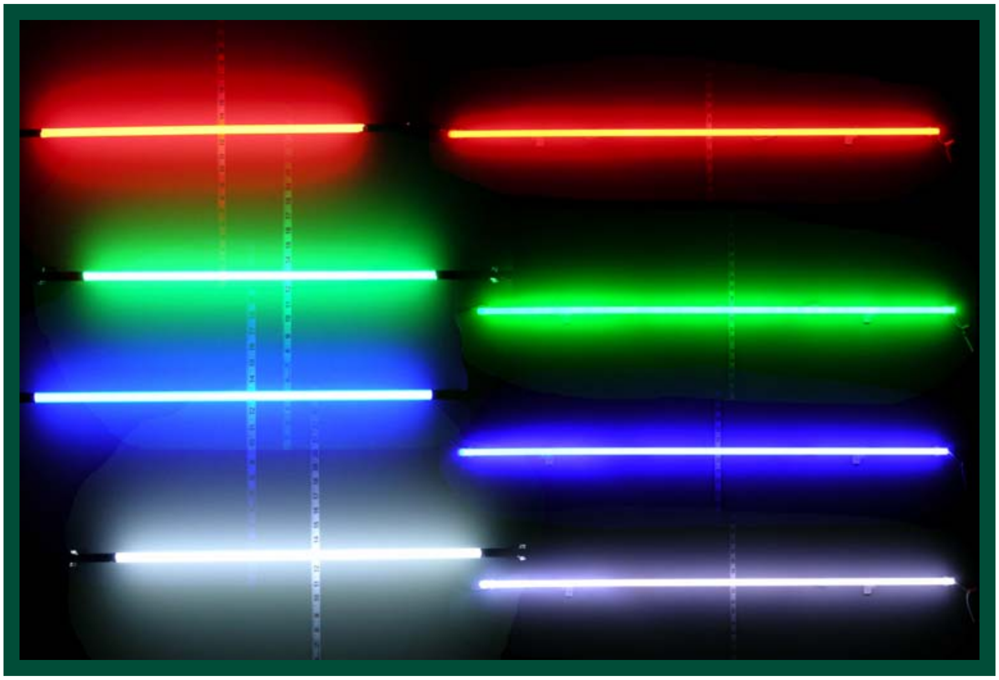
# LED Linear Architectural Lighting

*ET 06.17 Report*



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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| CCFL | Cold Cathode Fluorescent Light |
| CIE | International Commission on Illumination |
| CLTC | California Lighting Technology Center |
| D&ES | Design and Engineering Services |
| kWh | kilo-Watt-hours |
| LED | Light Emitting Diode |
| PQL | Power Quality Logger |
| SCE | Southern California Edison |
| SCLTC | Southern California Lighting Technology Center |
| THD | Total Harmonic Distortion |
| VAC | Volts Alternating Current |

# FIGURES

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# EXECUTIVE SUMMARY

Architectural linear neon, a form of cold cathode lighting, is a popular way to illuminate buildings and highlight interior spaces for a distinctive look. Many businesses, from fast food restaurants to theaters and casinos, use architectural linear lighting.

The objective of this project is to evaluate and demonstrate the demand, energy savings potential, and technical differences between traditional linear neon and emerging linear light-emitting diode (LED) technologies. This report will help illustrate potential market barriers for linear LED technology.

Overall, neon and LED products offer their own benefits and limitations. LED products generally consume less power, while neon products generally provide higher light output and greater efficiency, with the exception of LED red. Currently, neon has many more color choices than LED technology, but LED technology is generally more robust and safer due to plastic construction and low voltage electrical architecture.

Several linear neon and LED products from different manufacturers were tested and analyzed by color. The following characteristics were considered in the analysis.

- Power density
- Luminance
- Efficiency
- Power factor
- Current total harmonic distortion
- Color, and
- Contrast

Neon and LED products offer their own advantages and disadvantages. LED products have lower demand, while neon products have higher luminance and efficiency (excluding red). Neon dominates in color choice and standardized design, while LED offers more robust components and safer handling.

# INTRODUCTION

Linear neon lamps have been in use in the United States since 1923. In the past, neon was used in both indicator lamps and early electronic circuits as well. A light emitting diode (LED) is a newer technology traditionally used in indicator lamps but manufacturers are starting to use the technology in signage and general illumination.

## TECHNOLOGY DESCRIPTION

Neon and LED are two different technologies and each employ their own operational principals and design considerations.

### NEON – COLD CATHODE

The popular neon lamp is a form of cold cathode fluorescent light (CCFL) technology. Similar to the common fluorescent lamp, cold cathode lamps are comprised of gas in a glass tube with two electrodes on each end. These lamps are powered by a transformer and like the fluorescent lamp ballasts, the transformers come in the older magnetic form as well as the newer electronic variety. The transformer converts the incoming line voltage from the utility to a much higher voltage. The required voltage depends on many aspects of the lamp, or glass tube, such as gas fill, pressure, length, diameter, and preferred brightness. The neon glass tube dimensions, gas fill requirements, and transformer sizing are illustrated in charts provided by neon transformer manufacturers. Figure 1 shows a chart from FRANCE, a major supplier of neon transformers.

## LUMINOUS TUBE FOOTAGE CHART

**TRANSFORMER RATING** — **APPROXIMATE NUMBER OF FEET OF TUBING***

| Secondary Voltage (volts) | Short Circuit Current (milliamperes) | Clear or Fluorescent Red Neon (Also recommended for Neon Fluorescent Gold) Tube Size, Millimeters | | | | | | | | | | | Clear or Fluorescent Mercury Filled Tubes, All Colors All Enclosed Applications† Tube Size, Millimeters | | | | | | | | | | | Secondary Voltage (volts) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 25 | 22 | 20 | 18 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 25 | 22 | 20 | 18 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | |
| 15,000 | 60 | 102 | 85 | 78 | 72 | 60 | 54 | 50 | 45 | 40 | 36 | 32 | 120 | 100 | 90 | 80 | 72 | 64 | 60 | 54 | 48 | 44 | 39 | 15,000 |
| | 30 | 102 | 85 | 78 | 72 | 60 | 54 | 50 | 45 | 40 | 36 | 32 | 120 | 100 | 90 | 80 | 72 | 64 | 60 | 54 | 48 | 44 | 39 | |
| 12,000 | 60 | 79 | 67 | 61 | 55 | 45 | 42 | 39 | 35 | 32 | 29 | 26 | 95 | 79 | 70 | 62 | 55 | 50 | 46 | 42 | 38 | 35 | 31 | 12,000 |
| | 30 | 79 | 67 | 61 | 55 | 45 | 42 | 39 | 35 | 32 | 29 | 26 | 95 | 79 | 70 | 62 | 55 | 50 | 46 | 42 | 38 | 35 | 31 | |
| 10,500 | 30 | 73 | 62 | 55 | 48 | 39 | 36 | 34 | 31 | 28 | 25 | 22 | 88 | 73 | 63 | 54 | 48 | 43 | 40 | 37 | 33 | 30 | 27 | 10,500 |
| 9000 | 60 | 67 | 57 | 48 | 40 | 33 | 30 | 29 | 26 | 24 | 21 | 18 | 80 | 67 | 55 | 45 | 40 | 36 | 33 | 31 | 28 | 25 | 22 | 9000 |
| | 30 | 67 | 57 | 48 | 40 | 33 | 30 | 29 | 26 | 24 | 21 | 18 | 80 | 67 | 55 | 45 | 40 | 36 | 33 | 31 | 28 | 25 | 22 | |
| | 20 | | | | | 28 | 26 | 24 | 22 | 19 | 18 | 16 | | | | | 34 | 31 | 29 | 26 | 23 | 20 | 18 | |
| 7500 | 60 | 51 | 41 | 34 | 28 | 26 | 24 | 22 | 21 | 19 | 17 | 15 | 61 | 48 | 39 | 35 | 31 | 28 | 27 | 25 | 23 | 20 | 18 | 7500 |
| | 30 | 51 | 41 | 34 | 28 | 26 | 24 | 22 | 21 | 19 | 17 | 15 | 61 | 48 | 39 | 35 | 31 | 28 | 27 | 25 | 23 | 20 | 18 | |
| | 20 | | | | | 22 | 21 | 20 | 18 | 16 | 15 | 13 | | | | | 27 | 25 | 24 | 21 | 19 | 18 | 16 | |
| 6000 | 60 | 40 | 34 | 28 | 23 | 20 | 19 | 18 | 16 | 15 | 13 | 12 | 48 | 40 | 32 | 28 | 24 | 23 | 21 | 19 | 18 | 16 | 14 | 6000 |
| | 30 | 40 | 34 | 28 | 23 | 20 | 19 | 18 | 16 | 15 | 13 | 12 | 48 | 40 | 32 | 28 | 24 | 23 | 21 | 19 | 18 | 16 | 14 | |
| | 20 | | | | | 18 | 17 | 16 | 14 | 13 | 11 | 10 | | | | | 22 | 20 | 18 | 17 | 15 | 13 | 12 | |
| 5000 | 60 | 33 | 28 | 23 | 19 | 17 | 16 | 15 | 12 | 11 | 10 | 8 | 40 | 33 | 27 | 23 | 20 | 19 | 16 | 15 | 13 | 12 | 10 | 5000 |
| | 30 | 33 | 28 | 23 | 19 | 17 | 16 | 15 | 12 | 11 | 10 | 8 | 40 | 33 | 27 | 23 | 20 | 19 | 16 | 15 | 13 | 12 | 10 | |
| | 20 | | | | | 15 | 13 | 13 | 11 | 9 | 8 | 7 | | | | | 18 | 16 | 15 | 13 | 12 | 11 | 9 | |
| 4000 | 60 | 27 | 23 | 19 | 16 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 32 | 27 | 22 | 19 | 16 | 14 | 13 | 12 | 10 | 9 | 8 | 4000 |
| | 30 | 27 | 23 | 19 | 16 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 32 | 27 | 22 | 19 | 16 | 14 | 13 | 12 | 10 | 9 | 8 | |
| | 20 | | | | | 11 | 10 | 10 | 9 | 8 | 7 | 6 | | | | | 13 | 12 | 12 | 11 | 9 | 8 | 7 | |
| 3000 | 60 | 17 | 14 | 12 | 11 | 10 | 9 | 9 | 8 | 7 | 6 | 5 | 22 | 18 | 16 | 14 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 3000 |
| | 30 | 17 | 14 | 12 | 11 | 10 | 9 | 9 | 8 | 7 | 6 | 5 | 22 | 18 | 16 | 14 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | |
| | 20 | | | | | 8 | 8 | 7 | 6 | 5 | 4 | 4 | | | | | 10 | 9 | 8 | 7 | 6 | 5 | 5 | |
| 2000 | 30 | | | | | 7 | 6 | 6 | 5 | 5 | 4 | 4 | | | | | 9 | 8 | 8 | 7 | 6 | 5 | 5 | 2000 |
| | 20 | | | | | 6 | 5 | 5 | 5 | 4 | 3 | 3 | | | | | 7 | 7 | 7 | 6 | 5 | 4 | 4 | |
| Recommended Gas Pressure (mm/Hg) | | 6 | 7 | 7½ | 8 | 9 | 10 | 10 | 11 | 12 | 13 | 15 | 6 | 7 | 7½ | 8 | 9 | 10 | 10 | 11 | 12 | 13 | 15 | |

* Based on average grade of tubing. † Exposed & extremely cold climates may require that footage to be reduced by 10-20%.

NOTE 1: Deduct approximately 1 foot from above figures for each pair of electrodes.

NOTE 2: Recommended gas pressue for 10-foot-plus lengths. Increase 10% for tube lengths under 10 feet.

NOTE 3: The tube footage chart is a guide. Consult transformer application data in catalogue.

**FIGURE 1. NEON SIZING CHART**

Applying the proper voltage across the electrodes excites the gas and causes it to emit light. The color of light depends on the type of gas in the tube and the type of phosphor coating, if present, inside of the tube. For example, excited neon gas in a bare glass tube produces red light, while an excited Mercury-Argon mixture with a phosphor coating can produce other colors of light, depending on the phosphors. Although typically called neon, most non-red neon uses a Mercury-Argon mixture along with a phosphor.

### LED

A LED is a semiconductor device that emits light though electroluminescence. When there is proper electrical current in a LED, the electrons in the semiconductor material get excited and emit a specific color of light. The color depends on the elements or compounds doped in the semiconductor material.

In a linear LED system, the individual LED semiconductors are installed in a linear translucent plastic form. Depending on the manufacturer, the solid translucent material glows fairly evenly when lit, imitating a neon tube.

### APPLICATION AND INSTALLATION

Architectural linear neon is a popular way to outline buildings and highlight interior spaces for a distinctive look. Many businesses, from fast food restaurants to theaters and casinos, use architectural linear lighting.

Neon and LED technology offer similar installation methods. For long, straight runs of neon, two 4-foot sticks of glass are fused together for a total length of nearly 8 feet (94 inches). Straight lengths longer than 8 feet are uncommon due to shipping considerations. The tubes are typically attached to walls using wall-mounted clips that support the neon tubes.

LED technology comes in similar lengths, depending on the manufacturer. Each run is placed end-to-end and electrically connected for power. The mounting methodology varies by manufacturer, but typically comprises of unique wall-mounted clips that lock the LED segments in place.

## OBJECTIVE

The objective of this project is to evaluate and demonstrate the demand, energy savings potential, and technical differences between linear neon and LED. This project will help illustrate potential market barriers for linear LED technology.

Power and photometric aspects of the neon and LED technologies are assessed. The measured power variables are wattage, power factor, and current total harmonic distortion (THD) and the measured photometric variables are luminance and color. Luminance and power are used to calculate efficiency in order to compare and contrast the two technologies. Luminance is also used to demonstrate differing contrast.

# TECHNICAL APPROACH

## OVERVIEW

Testing was conducted in a darkroom at the Southern California Lighting Technology Center (SCLTC) in Irwindale. Both neon and LED products were mounted to test signs and connected to a regulated power source. Demand, power factor, and current THD were recorded with a power quality logger. Color and luminance were captured with chroma and luminance meters. Contrast data was collected with the Photolux system, which generates false color luminance maps. Because industry-wide test standards for linear architectural lighting do not exist, the following test procedure was developed with input from the sign industry, neon, and LED professionals.

## SETUP AND EQUIPMENT

### TEST FACILITY

All testing was conducted at the SCLTC in Irwindale. In partnership with the California Lighting Technology Center (CLTC) in Davis and cooperation with the lighting industry, lighting professionals, and the design-engineering community, SCLTC's mission is to foster the application of energy-efficient lighting and day-lighting technologies. Unique lighting and day-lighting test equipment, energy-efficient lighting displays, a model kitchen, and flexible black-out test areas enabled the evaluation and demonstration of the various lighting technologies and applications.

### TEST SIGNS

Two test signs were constructed by a local sign manufacturer for the purpose of this project. One sign was used for the neon products, while the other sign was used for the LED products. Each sign's cabinet measured 4 ½ feet wide, 2 feet tall and 8 ¼ inches deep. Both cabinets were made of steel sheet metal and had removable front and back panels that were painted flat gray to provide a uniform, diffuse, light-colored background for mounting and testing each product. The cabinets were supported by feet made of square aluminum tube, as illustrated in Figure 2.

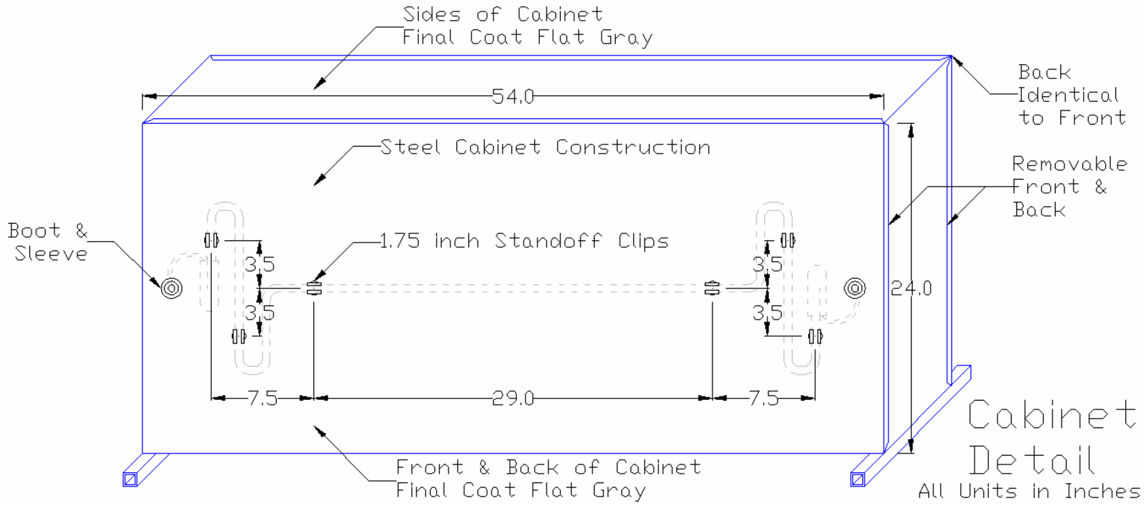



**FIGURE 2. CABINET DETAIL. BOTH TEST SIGNS USED THE SAME DIMENSIONS, CONSTRUCTION, AND PAINT**

### NEON TEST SIGN

The neon test sign cabinet featured six, 1 ¾ inch standoff clips on each of the two panels to support a total of two mounted neon glass units (one on each panel). Each panel also had two sleeved holes with high voltage wire running between the externally-mounted glass and internally-mounted transformers. The standoffs and holes were positioned to accommodate the 94-inch long glass units ordered from the neon manufacturers, as illustrated in Figure 3.

### LED TEST SIGN

The LED test sign cabinet featured blank (without standoff clips or holes) front and rear panels to accommodate the various mounting systems unique to each product. Four foot runs of product can be drilled and mounted to the front panel, with the remainder of connected product lying behind or below the sign with the transformer.

## DARKROOM

A darkroom provided a photometric-stable environment to ensure consistent, comparable measurements between each technology and product. Measurements were taken in a custom-built general-purpose darkroom that measured 15-feet deep, 6-feet wide and 7-feet high. The darkroom consisted of a collapsible frame made of a steel gas pipe painted flat black. The walls and roof were formed by an opaque diffuse covering of black stage curtains. With the stage curtains in place, ambient light levels inside the darkroom were well below 1 lux.

A 29-inch high table was centered along the back interior wall of the darkroom. Each test sign was centered on the table, with the feet flush with the front edge of the table. The darkroom also contained overhead lighting (that was turned off during testing), a work table for holding test equipment, and a computer for recording and downloading instrument data.

## REGULATED POWER SOURCE

In order to set and automatically maintain power supply at 120 Volts Alternating Current (Vac) for the duration of the testing, items were connected to a Staco Single Phase Voltage Regulator system (model number SLC-12WBSN005). The system is comprised of a motorized variable autotransformer, buck-boost transformers, an isolation transformer, a transient voltage suppressor, and an analog controller. Output voltage was verified with a Fluke 179 True RMS Digital Multimeter at the start of testing.

# PRODUCT EVALUATIONS

The following manufacturers and products were used to create averages for each color of neon and LED. Manufacturers are listed alphabetically. This order purposely does not correspond to the order of results listed in other sections of the report. Other than this section, products are consistently identified by an assigned number to keep from identifying the results of one manufacturer over another.

## NEON

Neon, including Mercury-Argon gas fills, was the baseline technology. Glass units were ordered from two manufacturers: The Creative Sign Company in Covina, California, and EGL Company Inc. in Berkeley Heights, New Jersey. Each glass unit was manufactured to the dimensions shown in Figure 3, and had a diameter of 15 millimeters, and a total length of nearly 8 feet (94 inches), which is common in linear neon installations. The glass units were bent at the ends for easier handling and to produce a smaller footprint. Measurements were only taken at the center of the straight stretch in the middle of each glass unit. Each of the colors in Table 1 was tested.

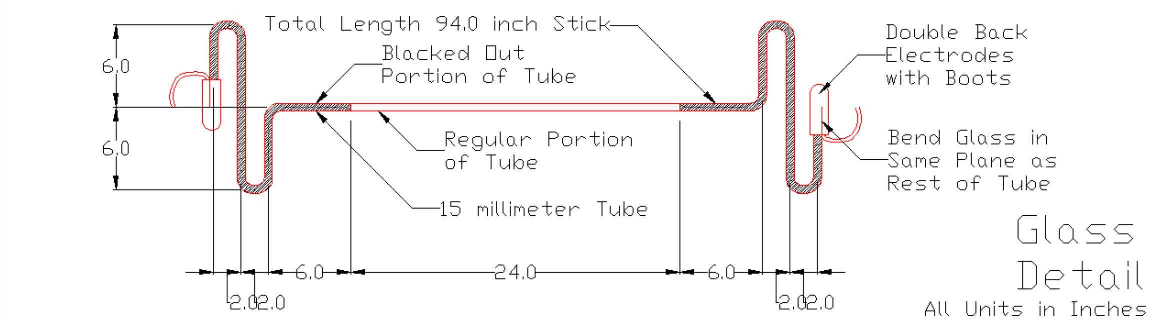



FIGURE 3. GLASS DETAIL

TABLE 1. NEON MANUFACTURERS AND COLORS TESTED

| Manufacturer | Color (94 Inches Long, 15 Millimeters) |
|---|---|
| Creative | Red |
| Creative | Orange |
| Creative | Yellow |
| Creative | Green |
| Creative | Blue |
| Creative | White |
| EGL | Ruby red* (red) |
| EGL | Orange |
| EGL | Casino gold* (yellow) |
| EGL | Tropic green* (green) |
| EGL | Horizon blue* (blue)<br>*color names from manufacturer |

Each color was tested with an electronic and magnetic transformer with the glass unit's wired-in series. Electric current flowed from the transformer, to the first glass unit, to the second glass unit, then back to the transformer as shown in Table 2 Transformers were selected using manufacturers' sizing charts for proper loading with two glass units connected. For each manufacturer, the transformer was connected to the color on the front of the tested cabinet and the yellow tube on the back of the cabinet from that same manufacturer. When yellow was the tested color on the front of the cabinet, the blue tube was connected on the back of the cabinet. This ensured that each color from a specific manufacturer was always tested with the same yellow tube from the same manufacturer to consistently load the transformer, as shown in Table 3.

**TABLE 2. NEON TRANSFORMERS - TESTED WITH AN ELECTRONIC AND MAGNETIC TRANSFORMER**

| TYPE | DESCRIPTION |
|---|---|
| Electronic | Ventex Generation III 6 kV 30 mA (VT6030CL-120) |
| Magnetic | France Smart 5 kV 30 mA (5030 P5G-2E) |

**TABLE 3. NEON TRANSFORMER LOADING AND COLOR COMBINATIONS. YELLOW OR BLUE WAS USED TO CONSISTENTLY LOAD THE TRANSFORMER.**

| Manufacturer | Transformer | Tested Color | Additional Loading For Color |
|---|---|---|---|
| Creative | Electronic | Red | Yellow |
| Creative | Electronic | Orange | Yellow |
| Creative | Electronic | Green | Yellow |
| Creative | Electronic | Blue | Yellow |
| Creative | Electronic | White | Yellow |
| Creative | Electronic | Yellow | Blue |
| Creative | Magnetic | Red | Yellow |
| Creative | Magnetic | Orange | Yellow |
| Creative | Magnetic | Green | Yellow |
| Creative | Magnetic | Blue | Yellow |
| Creative | Magnetic | White | Yellow |
| Creative | Magnetic | Yellow | Blue |
| EGL | Electronic | Red | Yellow |
| EGL | Electronic | Orange | Yellow |
| EGL | Electronic | Green | Yellow |
| EGL | Electronic | Blue | Yellow |
| EGL | Electronic | Yellow | Blue |
| EGL | Magnetic | Red | Yellow |
| EGL | Magnetic | Orange | Yellow |
| EGL | Magnetic | Green | Yellow |
| EGL | Magnetic | Blue | Yellow |
| EGL | Magnetic | Yellow | Blue |

## LED

LED products were ordered from four manufacturers, with one manufacturer offering two product lines: GE Contour LS, iLight Plexineon, Sloan ColorLine, Sloan LEDStripe, and US LED Accent 2. Each product was ordered in 4-foot segments along with recommended transformers, wiring components, and mounting hardware. GE Contour LS was ordered in 8-foot segments, and were cut to 4-foot segments according to the manufacturer's instructions. Measurements were taken at the center of each segment, and each of the colors in Table 4, below, was tested.

**TABLE 4. LED MANUFACTURERS, SERIES, AND COLORS TESTED**

| Manufacturer | Series | Color (4-Foot Segments) | Rated W/ft |
|---|---|---|---|
| GE | Contour LS | Red (8 foot segment*) | 3.81 |
| GE | Contour LS | Green (8 foot segment*) | 3.39 |
| GE | Contour LS | Blue (8 foot segment*) | 3.39 |
| GE | Contour LS | White (8 foot segment*)<br>*GE supplied only 8 foot segments | 3.39 |
| iLight | Plexineon | Red (white diffuser) | 1.92 |
| iLight | Plexineon | Daytime red (red diffuser) | 1.92 |
| iLight | Plexineon | Orange | 1.92 |
| iLight | Plexineon | Yellow | 1.92 |
| iLight | Plexineon | Green | 2.59 |
| iLight | Plexineon | Blue | 2.59 |
| iLight | Plexineon | White | 2.59 |
| Sloan | ColorLine | Red | 2.28 |
| Sloan | ColorLine | Orange | 2.28 |
| Sloan | ColorLine | Yellow | 2.28 |
| Sloan | ColorLine | Green | 2.28 |
| Sloan | ColorLine | Blue | 2.28 |
| Sloan | ColorLine | White | 2.28 |
| Sloan | LEDStripe | Red | 2.8 |
| Sloan | LEDStripe | Orange | 2.8 |
| Sloan | LEDStripe | Yellow | 2.8 |
| Sloan | LEDStripe | Green | 2.8 |
| Sloan | LEDStripe | Blue | 2.8 |
| Sloan | LEDStripe | White | 2.8 |
| US LED | Accent 2 | Red | 1.965 |
| US LED | Accent 2 | Orange | 1.965 |
| US LED | Accent 2 | Yellow | 1.965 |
| US LED | Accent 2 | Green | 1.74 |
| US LED | Accent 2 | Blue | 1.74 |
| US LED | Accent 2 | White | 1.92 |

Each color was tested with the manufacturer's recommended transformer and wiring. In all cases, a total of 16 feet of wiring was connected at a time to place a noticeable load on the transformer. All connected segments had the same rated watts per foot (power density) to enable later analysis and calculation of actual power density from the demand measurements. For example, the US LED Accent 2 colors were from the same manufacturer and same product line. However, red, orange, and yellow had a different power density (1.965 W/ft) than green and blue (1.74 W/ft), that was different from white (1.92 W/ft), as shown in the Rated W/ft column in Table 4. In order to connect 16 feet of Accent 2 with the same power density, project staff ordered a minimum of 16-feet segments with the same power density, as shown in the Feet Ordered column in Table 4. For instance, when testing Accent 2 yellow (1.965 W/ft), one segment of Accent 2 orange (1.965 W/ft) and two segments of Accent 2 red (1.965 W/ft) were connected to get a total of 16-feet of uniform power density load on the transformer. Accent 2 white had a power density of 1.92 W/ft, which was different from any of the other colors. Therefore, a full 16 feet of white was ordered for the test.

Due to low volume procurement problems, GE Contour LS red and white were the only products not tested with uniform-rated power density. Contour LS red had a power density of 3.81 W/ft, while green, blue, and white were 3.39 W/ft. Green and blue were tested together to get 16 feet of uniform power density. However, red and white were tested together, creating a non-uniform power density, with a difference of 0.42 W/ft between the red and white segments.

## DEPENDENT VARIABLES AND EQUIPMENT

The following equipment and measurements were used with each product and color.

### DEMAND, POWER FACTOR, AND CURRENT THD

Demand (watts), power factor (ratio of real power to apparent power), and current THD (amperes percent THD) were recorded with an AEMC Instruments Power Quality Logger (PQL) 120, as shown in Figure 4. The logger was installed in series between the regulated power source and the neon/LED transformer, and configured to record every second for a period of 30 minutes after turning on each product. After logging stopped, the data was downloaded to the computer and exported for later analysis.


**FIGURE 4. POWER QUALITY LOGGER**

## COLOR AND LUMINANCE

Color ([x, y] chromaticity coordinates) was measured with a Konica Minolta CS-100A chroma meter, as shown in Figure 5. The meter was mounted on a tripod, with the lens centered horizontally and vertically at a distance of 38 inches from the center of the product. This distance was determined by the capability of the meter to take accurate measurements in close proximity to the product, while still completely filling the viewfinder's target area of measurement with the product. For example, with the lens closer than 36 inches to the product, the target area of measurement is completely filled with product, which helps eliminate the effects of including background in the measurement area. However, at this distance, the meter is unable to focus and accurately measure. Similarly, with the lens farther than 40 inches from the product, the meter is able to focus and accurately measure. However, at this distance, the target area of measurement is not completely filled with product, but instead, includes the background behind the product, which causes undesirable changes to the measurements. This concept is outlined in Table 5

**TABLE 5. COMPARISON OF CHROMA METER DISTANCES TO PRODUCT. THE REGION AROUND 38 INCHES IS THE ONLY REGION WITH COMPLETELY DESIRABLE RESULTS.**

| Distance To Product | < ~ 38 Inches | = ~ 38 Inches | > ~ 38 Inches |
|---|---|---|---|
| Target area of measurement | Completely filled with product | Completely filled with product* | Includes product with background |
| Focus | Out of focus | In focus | In focus |
| Luminance accuracy | Inaccurate | Accurate | Accurate but includes background |
| Color accuracy | Accurate | Accurate | Accurate |

*The target area of measurement is completely filled by products with larger diameters only. Due to the inclusion of background in the target area of measurement, the chroma meter measures color accurately, but luminance inaccurately for products with smaller diameters. Refer to Figure 5 for an explanation of how this was overcome.

**FIGURE 5. CHROMA METER. THE CHROMA METER MEASURES COLOR AND LUMINANCE.**

Depending on the diameter of the product being measured, luminance (candelas per square meter) was measured with a Konica Minolta CS-100A chroma meter (as shown in Figure 5). This meter was also mounted on a tripod, with the lens centered horizontally and vertically at a distance of 38 inches from the center of the product. Each meter contains a viewfinder with a circular target designating the area of actual measurement. The chroma meter has a larger target diameter and a correspondingly larger area of measurement than the luminance meter. Therefore, for products with larger diameters where the thickness of the product completely fills the target, the chroma meter was able to be used to measure luminance simultaneously with color. Luminance for Creative neon, EGL neon, and US LED Accent 2 was measured with the chroma meter. However, for products with smaller diameters where the thickness of the product did not completely fill the target of the chroma meter, the luminance meter was used to measure luminance separate from color. Luminance for iLight Plexineon, Sloan LEDStripe, Sloan ColorLine, and GE Contour LS was measured with the luminance meter, as shown in Table 6.

**TABLE 6. COMPARISON OF LUMINANCE METER AND CHROMA METER**

| Meter | Chroma (CS-100A) | Luminance (LS-110) |
|---|---|---|
| Capabilities | Luminance and color | Luminance only |
| Target area of measurement | Larger | Smaller |
| Used to measure luminance for | Larger diameter:<br>Creative neon<br>EGL neon<br>US LED Accent 2 | Smaller diameter:<br>iLight Plexineon<br>Sloan LEDStripe<br>Sloan ColorLine<br>GE Contour LS |
| Used to measure color for | All products | N/A, Can't measure color |

**FIGURE 6. LUMINANCE METER**

Color and luminance measurements were taken several consecutive times to ensure consistency and accuracy, and then manually recorded for later analysis. All measurements were taken after the 30-minute startup period.

## CONTRAST

Contrast was measured with the Photolux system, consisting of a Nikon Coolpix 5400 digital camera and Photolux luminance mapping software. The camera was mounted on a tripod, with the lens centered horizontally and vertically at a distance of 42 inches from the center of the product. This distance was determined by the capability of the camera to include a view of the entire height of the sign without use of a fisheye lens. Normally, the Photolux system uses a fisheye lens to include surrounding features. Since this test was only concerned with the luminance on the front of the test sign cabinet, the camera was used without a fisheye lens to increase the resolution of the area directly above and below the product. A cloth measuring tape was attached to the front of the test sign cabinet to aid in later analysis.

The Photolux system uses the camera's charge-coupled device (CCD) as an array of light sensors. By taking a set of 14 pictures at the exposure settings shown in Table 7, the calibrated Photolux luminance mapping software can create a false-color luminance map, as shown in the Results and Analysis section.

**TABLE 7. LUMINANCE CAMERA EXPOSURE SETTINGS**

| Picture | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shutter Speed | 2 | 1 | 1/2 | 1/4 | 1/8 | 1/15 | 1/30 | 1/60 | 1/125 | 1/250 | 1/500 | 1/1000 | 1/2000 | 1/4000 |
| Aperture | 2.8 | 3.1 | 3.5 | 4 | 4.4 | 5 | 5.6 | 6.3 | 5.6 | 5 | 5.6 | 6.3 | 7.1 | 7.9 |

# RESULTS

Neon and LED products offer their own advantages and disadvantages. LED products have lower demand, while neon products have higher luminance and efficiency (excluding red). Neon dominates in color choice and standardized design, while LED offers more robust components and safer handling.

## POWER DENSITY

Lower power densities are generally more desirable than higher ones, since power density has a direct link to the demand, efficiency, and energy usage of a product, as shown in Equation 1, Equation 2, and Equation 5. For all colors, the average power density for LED is approximately 26% lower than electronic neon and approximately 44% lower than magnetic neon. If the sole purpose of a linear border tubing installation is to reduce demand, LED has a clear advantage over neon.

## LUMINANCE

Luminance is a measure of the brightness of the product and is more of a qualitative measurement than a quantitative one. Brighter products are more likely to attract attention and stand out against other light sources and backgrounds. However, too bright a product may be unreadable and cause glare and discomfort. For blue, green, orange, white, and yellow, the dimmest neon is still brighter than the brightest LED. However, for red, the average LED is noticeably brighter than the average neon. If the sole purpose of a linear border tubing installation is to increase brightness, neon has a clear advantage over LED for all colors except red. For red, LED has a clear advantage over neon. Average differences in brightness are shown in Table 8.

**TABLE 8. AVERAGE LUMINANCE DIFFERENCE BETWEEN LED AND NEON**

| Color | LED Compared To Electronic Neon | LED Compared To Magnetic Neon |
|---|---|---|
| Blue | 466% lower | 498% lower |
| Green | 460% lower | 463% lower |
| Orange | 127% lower | 139% lower |
| Red | 59% higher | 44% higher |
| White | 174% lower | 171% lower |
| Yellow | 300% lower | 304% lower |

## EFFICIENCY

Higher efficiency is more desirable than lower efficiency, since efficiency indicates how resourceful the product is with each Watt of power, as shown in Equation 2. A product may have low demand, but if it also has very low luminance, its efficiency will suffer. In order for an energy-saving product or technology to replace a baseline product or technology, the replacement product's efficiency must be equal to or higher than the baseline's. Otherwise, demand is sacrificed at the expense of luminance, or vice versa. For blue, green, white, and yellow, the least efficacious neon is more efficacious than the most efficacious LED, while for orange, the average neon is more efficacious than the average LED. One orange LED manufacturer had a more efficacious product than all others except the most efficacious neon. For red, the average LED product is more efficacious than the average neon product. From an efficiency standpoint, neon has a clear advantage over LED for all colors except red. One orange LED manufacturer may be able to compete with neon. For red, LED has a clear advantage over neon. Average differences in efficiency are shown in Table 9.

**TABLE 9. AVERAGE EFFICIENCY DIFFERENCE BETWEEN LED AND NEON**

| Color | LED Compared To Electronic Neon | LED Compared To Magnetic Neon |
|---|---|---|
| Blue | 424% lower | 385% lower |
| Green | 420% lower | 365% lower |
| Orange | 71% lower | 59% lower |
| Red | 99% higher | 102% higher |
| White | 136% lower | 103% lower |
| Yellow | 212% lower | 175% lower |

## POWER FACTOR

Higher power factor is more desirable than lower power factor, since power factor indicates how much more current is needed for the same amount of usable power delivered. A product with high power factor will draw less current than a product doing the same job with a lower power factor. Higher power factor minimizes transmission and distribution currents, which reduces transmission losses and equipment size. In turn, this makes the delivery of electricity more efficient and less costly. For all colors, the average power factor for LED was approximately 13% lower than electronic neon and approximately 118% higher than magnetic neon. If the sole purpose of a linear border tubing installation is to increase power factor, LED has a clear advantage over magnetic neon and a slight advantage over electronic neon.

## CURRENT THD

Lower current THD is more desirable than higher current THD, since current THD is a measure of the distortion of the alternating current Voltage source current waveform. A product with lower harmonic distortion will have a cleaner current signal than a product with higher harmonic distortion. Lower distortion reduces line noise, minimizes erratic circuit behavior, and possibly reduces detrimental affects on other devices connected to the same circuit. For all colors, the average current THD for LED is approximately 94% higher than electronic neon and approximately 600% higher than magnetic neon. If the sole purpose of a linear border tubing installation is to decrease current THD, neon has a clear advantage over LED.

## COLOR

Color is a qualitative measurement. The ideal chromaticity of a product is subjective to the desired effect and the preferences of the customer. Therefore, it is impossible to conclude that one shade of a particular color is superior to another. This is especially true when comparing neon and LED. While the neon tested for this project was limited to six standard colors, neon is available in a multitude of other colors, which vary greatly by manufacturer. On the other hand, LED is very limited in color choices, but each color still varies by manufacturer.

Assuming the neon products in this test are to be replaced with equivalently-colored LED products, orange, red, and white can be replaced with no noticeable change in color. However, the blue, green, and yellow neon can not be matched with LED, as illustrated in Table 8 and Figure 38. This is especially true of yellow, where the neon yellow is very pure and the LED yellow is more similar to gold or orange. Therefore, if a neon product is being replaced with LED, color matching may be a problem, especially with non-primary colors. LED's limited color palette gives neon a significant advantage, especially when matching corporate branding requirements or artistic desires.

## CONTRAST

Similar to color, contrast is also a quantitative measurement, but the ideal contrast of a product is subjective to the desired effect and preferences of the customer. Therefore, it is impossible to conclude that one contrast effect is superior to another. In some cases, the customer may want the traditional neon halo effect caused by illuminating the background around the border tubing. In other cases, a highly contrasting, sharp line of color against an unlit background may be desired.

Again, assuming the neon products in this test are to be replaced with equivalently-contrasting LED products, only some LED manufacturers create a halo effect due to the design of their product, as illustrated in Figure 41 through Figure 45. Other LED manufacturers create a highly contrasting, sharp line of color with no background illumination.

# General Considerations

From an ordering, handling, installation, operation, and maintenance standpoint, both neon and LED offer their own unique advantages and disadvantages.

## Ordering

Both neon and LED are equivalently easy to specify and order, requiring a basic knowledge of lighting and electricity. Both technologies require transformers, various accessories for proper installation and operation, and the parameters of the design such as run lengths and corner radii. With neon, additional parameters such as tube diameters, unique shapes, gas pressures, and electrode types can be specified for more custom installations, such as logos or curved buildings. Generally, LED products are available in rigid straight runs and semi-flexible, formable runs for corners.

## Handling

Neon tubes are universally made of glass, while LED segments are usually made of different types of plastic diffusers with metal channels. As a result, neon must be shipped in highly protective packaging and handled carefully in the field. LED can be shipped with standard protection and handled fairly roughly in the field. Auxiliary components for both technologies, such as transformers, wiring, and mounting hardware, are similarly durable.

## Installation and Operation

Neon involves very high voltages, usually in the 5 kV or higher range on the secondary side of the transformer. This requires special care during installation to ensure all connections meet applicable electrical codes and industry safety standards. High voltage wires, insulators, and clearances must be used. On the other hand, LED typically operates at very low voltages in the 24 volt or less range on the secondary side of the transformer. This exempts it from certain electrical codes, though care should still be taken to minimize the potential for short circuits and fire.

Neon tubes must be formed and charged with gas at the factory. Once cooled and sealed, the glass units are not serviceable or formable. However, many LED products can be field-cut to the desired length (within a manufacturer specified cut increment), while some can be ordered in flexible form for rounded corners or basic designs.

Additionally, due to the high voltages involved and sharp glass edges, neon needs to be well out of the way of accidental contact or breakage. The plastic construction of LED products makes them less susceptible to breakage, and less dangerous than glass, if broken.

Both neon and LED products require mounting hardware that is laid out and installed prior to installing the actual tubes or segments. The number of parts and time involved is similar for both, as long as the LED does not need to be field cut or formed.

## Maintenance

High voltages of neon require that the circuit be de-energized prior to replacing any components. Low voltage LED products can be safely handled and wired while energized, as long as care is taken not to create a short circuit (which may damage the transformer or LED segments). Because neon and LED components such as transformers, wiring, and mounting hardware are standardized, replacement parts can be obtained and interchanged from a variety of manufacturers and suppliers. On the other hand, all LED products are proprietary to varying degrees. Almost all require the use of proprietary mounting hardware, while some can be used with standard neon mounting hardware. Almost all recommend the use of a manufacturer-supplied transformer, though some third-party transformers of the same specifications may work. Depending on the lifetime of the LED products, getting replacement parts or matching existing installations may be problematic several years after the initial installation.

# LIMITATIONS

Future studies should address the following limitations of this project. These limitations should also be considered when drawing on the results and conclusions contained in this report.

## SMALL NEON SAMPLE SIZE

While five LED product series from four major linear LED manufacturers were tested, only two neon manufacturers were used to establish a baseline. Furthermore, the baseline established by the neon manufacturers had a wide range of results, obvious in situations such as Figure 14, where Neon 1 measured over 2000 candelas per square meter and Neon 2 measured less than 1500 candelas per square meter. However, this was considered acceptable to project management, since the difference represented the extremes of neon products: those available from high quality and premium manufacturers and those available from generic and average manufacturers. This difference was always averaged first and then compared to the average for LED.

## ONE NEON WHITE MANUFACTURER

Only one white neon product from one manufacturer was tested to establish a white neon baseline, since white was not supplied by the other neon manufacturer. This is a significant limitation, since the white neon baseline may be very different for other manufacturers. This should be considered when reviewing the results for white neon and LED products.

## DIFFERENCES BETWEEN MAGNETIC AND ELECTRONIC NEON

Throughout this project, neon was tested with both magnetic and electronic transformers, and then compared separately to LED. Therefore, the differences between magnetic and electronic neon transformers was recorded but not specifically analyzed since this type of analysis was not the focus of the project.

# OVERALL DISCUSSION

Linear neon and LED border tubing represent two very different technologies with the intention of accomplishing the same task. Both offer clear advantages and disadvantages, with little overlap. From a utility energy efficiency program perspective, the greater efficiency of red LED products makes them an attractive candidate for inclusion in incentive programs. However, neon still dominates performance in other colors, where LED technology is not ready as a neon baseline replacement. One LED manufacturer makes an orange product that competes well with the efficiency of orange neon, but the average orange LED still lags behind. Also, LED does not offer the color flexibility of neon, which is important when matching corporate branding requirements and meeting artistic desires. However, if demand and energy reduction are the more important factors in designing a border tubing installation, LED is a clear winner, though it is less energy efficient (excluding red).

As illustrated in Figure 7, a comparison of luminance and efficiency, some colors and product series of LED are in the same range as neon. However, only neon is present in the upper right corner of the graph, indicating higher luminance and efficiency. This brings the average for neon higher than that of LED, as shown in Table 9.

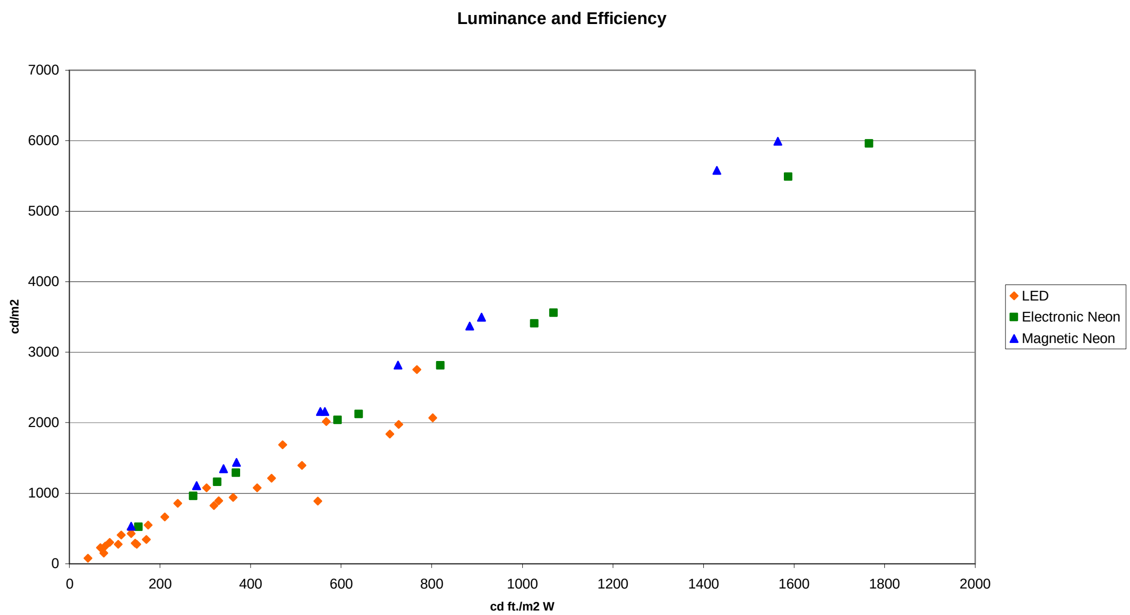



**FIGURE 7. LUMINANCE AND EFFICIENCY**

# RECOMMENDATIONS

Both technologies, especially LED, are in a continual state of change and improvement. Variations in manufacturing processes, suppliers, and designs may improve the performance of future products. A similar project, or perhaps a phase 2 of this study, should be conducted in the future to discover any changes in either product.

# APPENDIX A: DETAILED RESULTS AND ANALYSIS

## OVERVIEW

Results from the Technical Approach were analyzed for the Conclusion. Products were consistently identified by an assigned name and number to mask their specific manufacturer and prevent direct comparison of results. For example, Creative neon may be identified as Neon 9, while Sloan ColorLine may be identified as LED 8 (neither of these numbers actually exists in the results).

## POWER DENSITY

Power density (watts per foot) was calculated by taking the average of the 29$^{th}$ minute of demand data for each product and dividing it by the total length of connected product (usually around 16 feet). For example, the power density of Neon 1 Electronic Blue was calculated using Equation 1.

**EQUATION 1. POWER DENSITY FOR NEON 1 ELECTRONIC BLUE**

$$PowerDensity = \frac{AverageLastMinuteOfDemandData}{LengthOfConnectedProduct} = \frac{52Watts}{15.7Feet} = 3.3WattsPerFoot$$

Assuming the rated power density of each connected segment was uniform, this normalized the demand data regardless of the exact length of connected load. Power density for each color was used later when calculating efficiency. The following graphs show the power density for each color and each manufacturer. The same power density calculation was taken for each of the other colors; green, orange, yellow, white, and red. Data was grouped by technology and then sorted within each technology from highest to lowest.

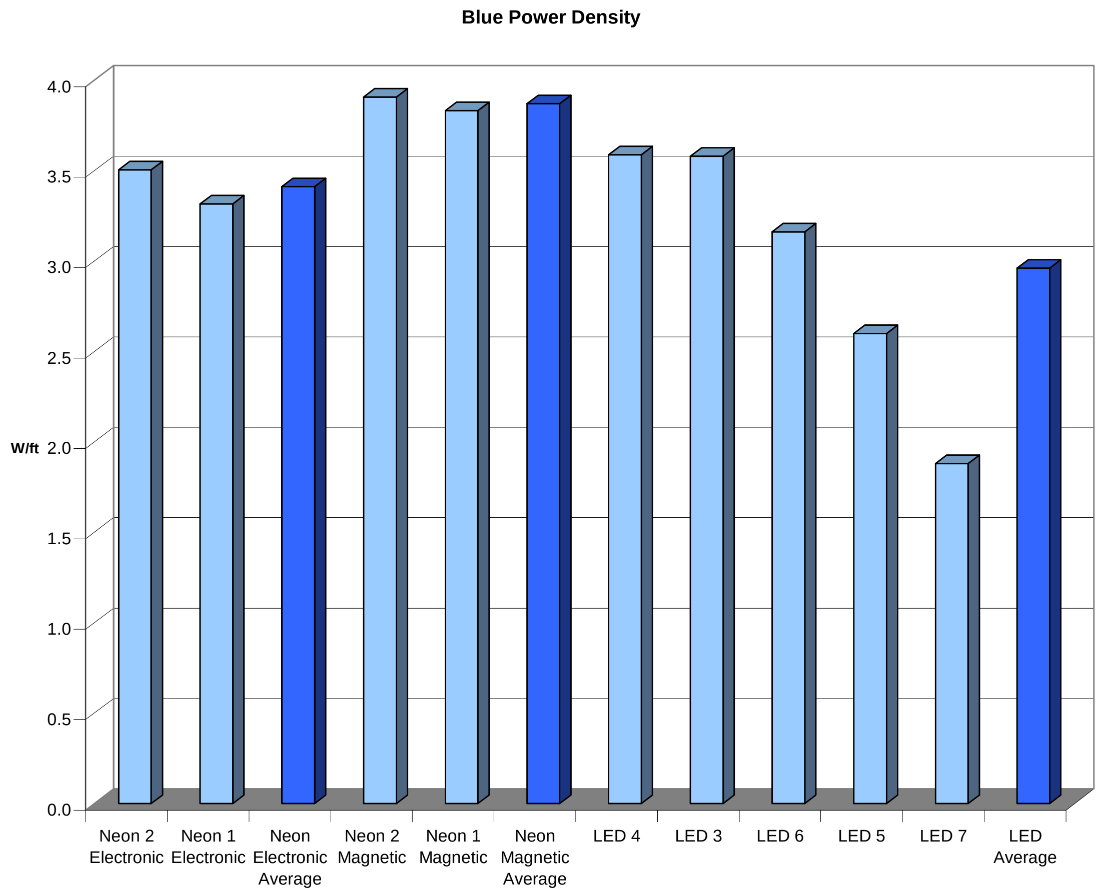



FIGURE 8. BLUE POWER DENSITY.

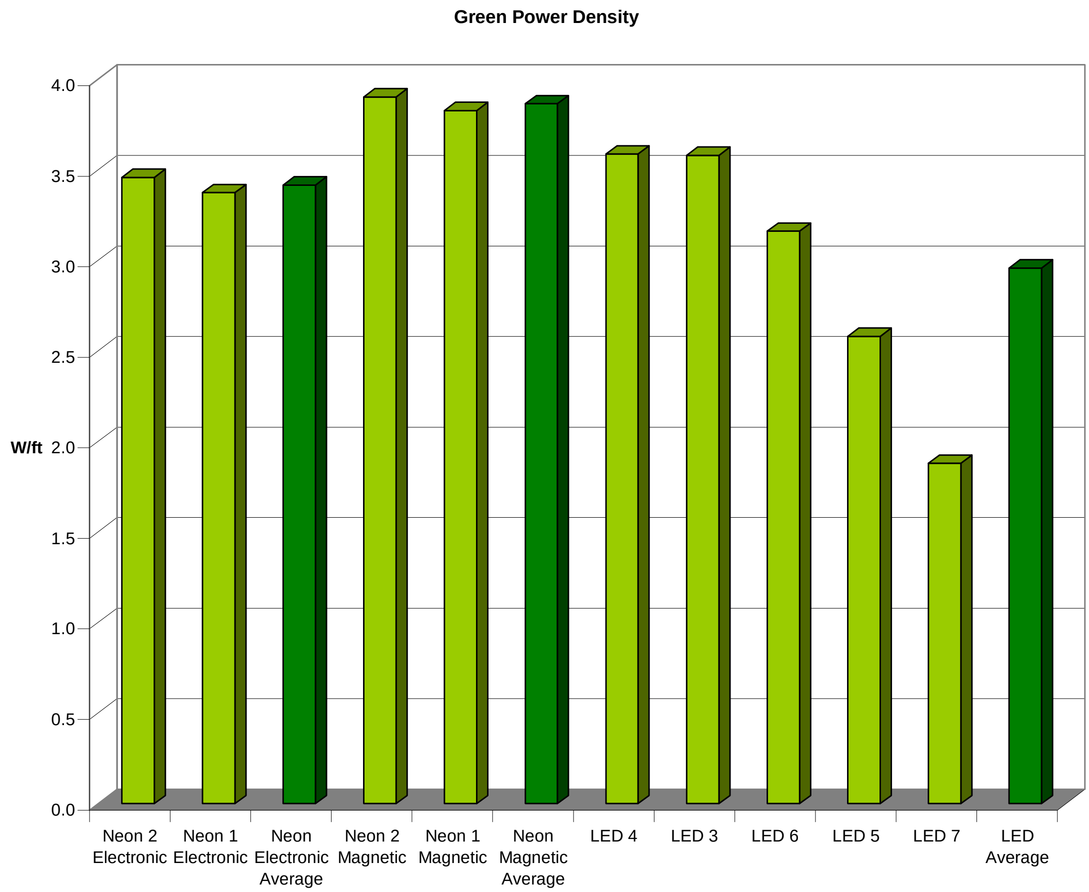



**FIGURE 9. GREEN POWER DENSITY**

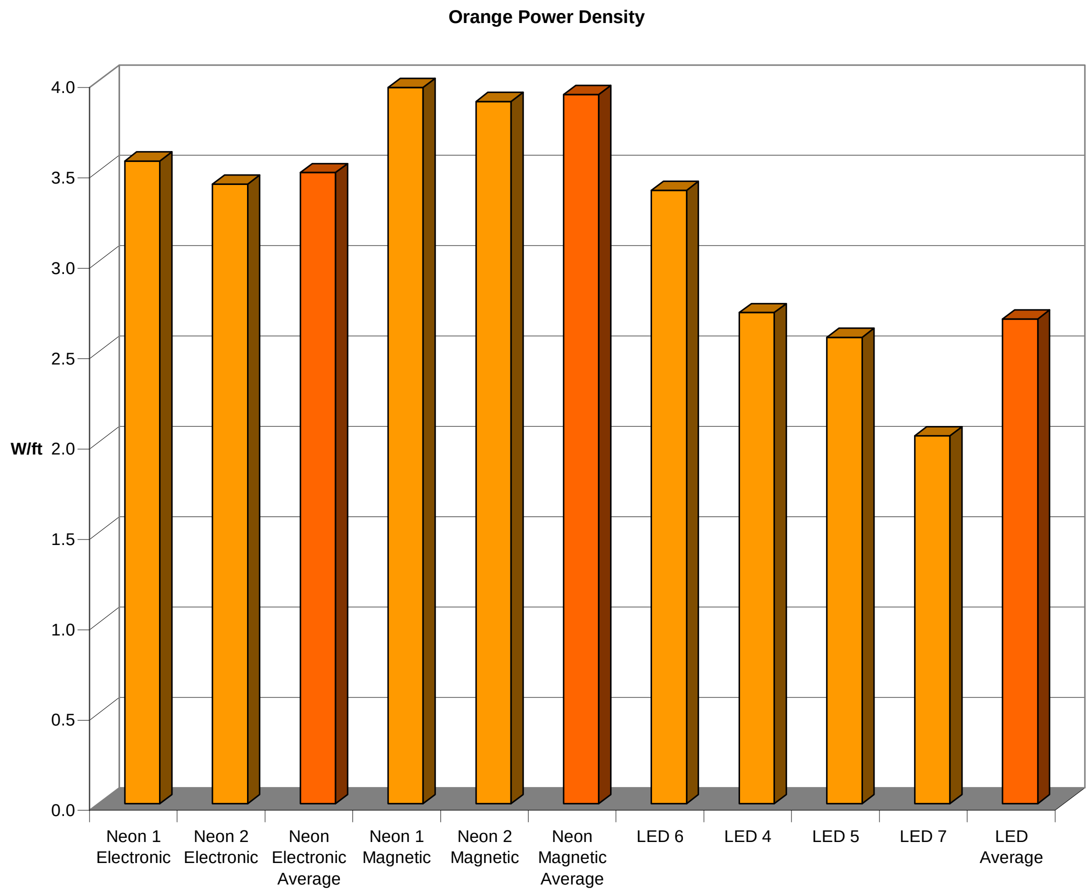



**FIGURE 10. ORANGE POWER DENSITY**

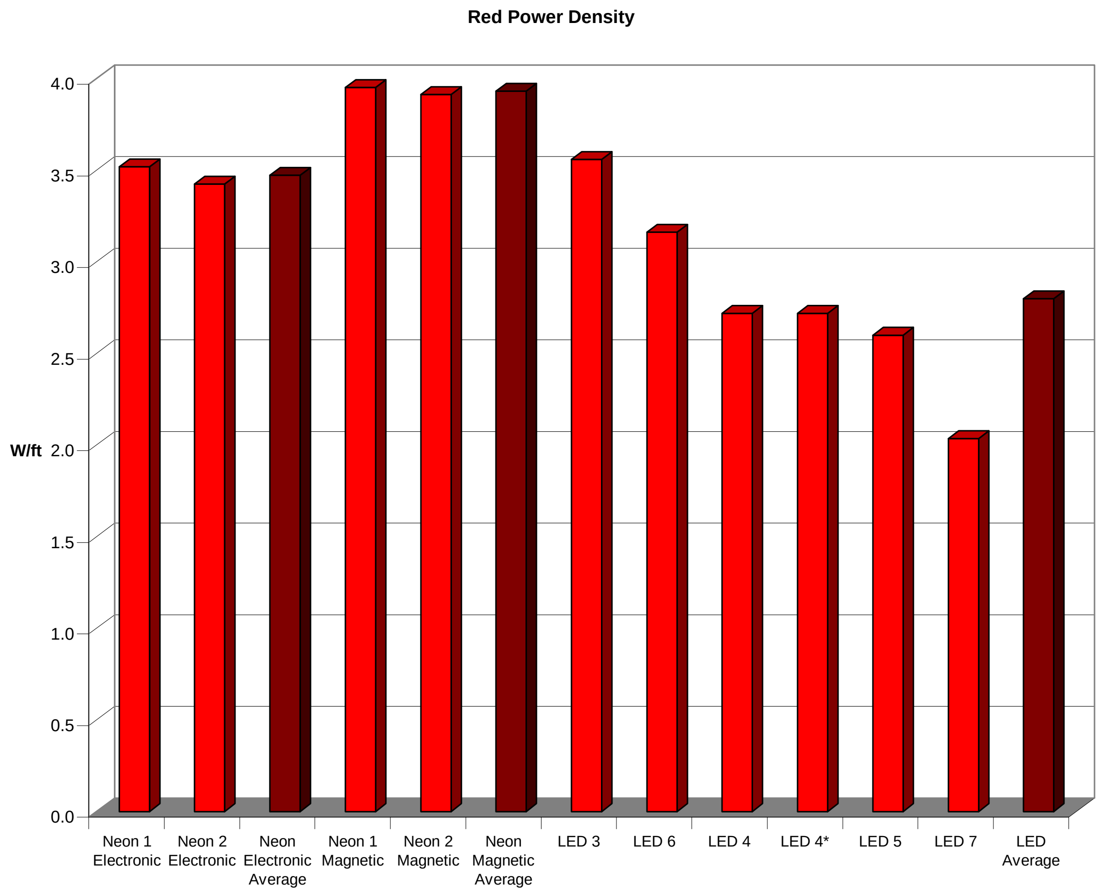



**FIGURE 11. RED POWER DENSITY**

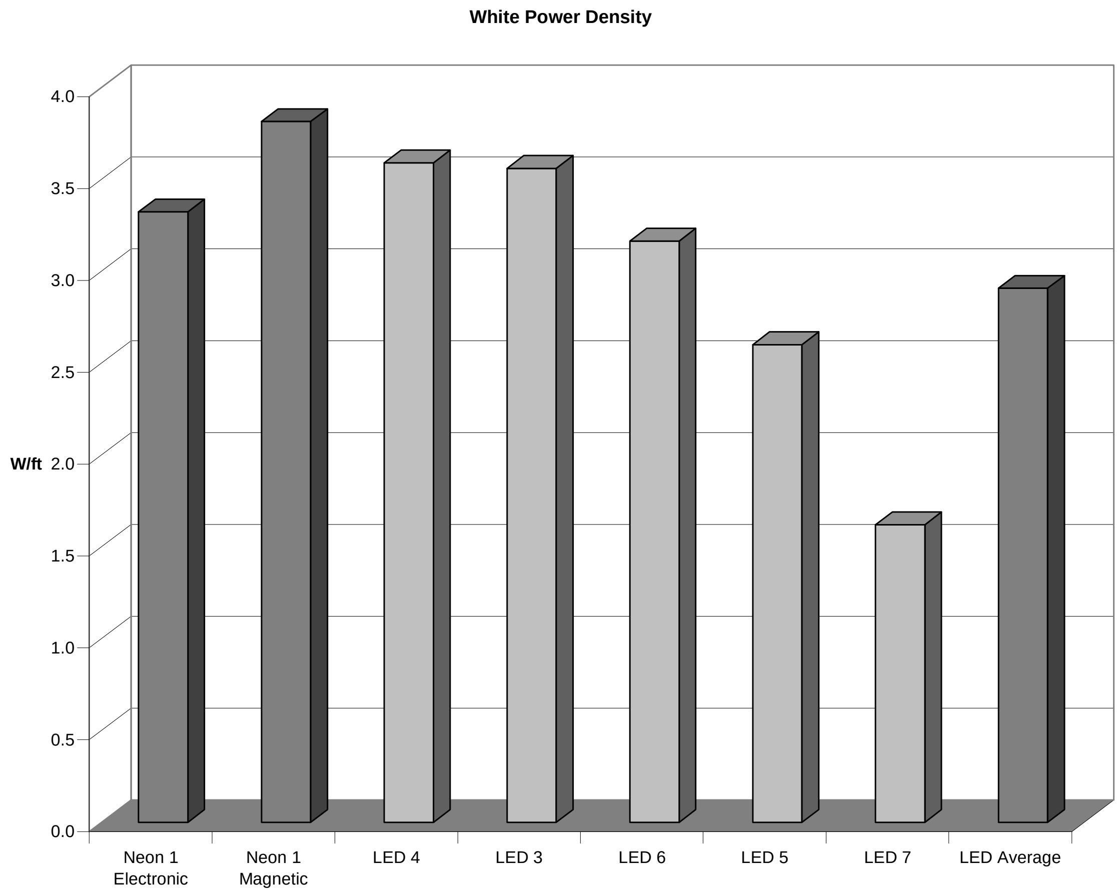



**FIGURE 12. WHITE POWER DENSITY**

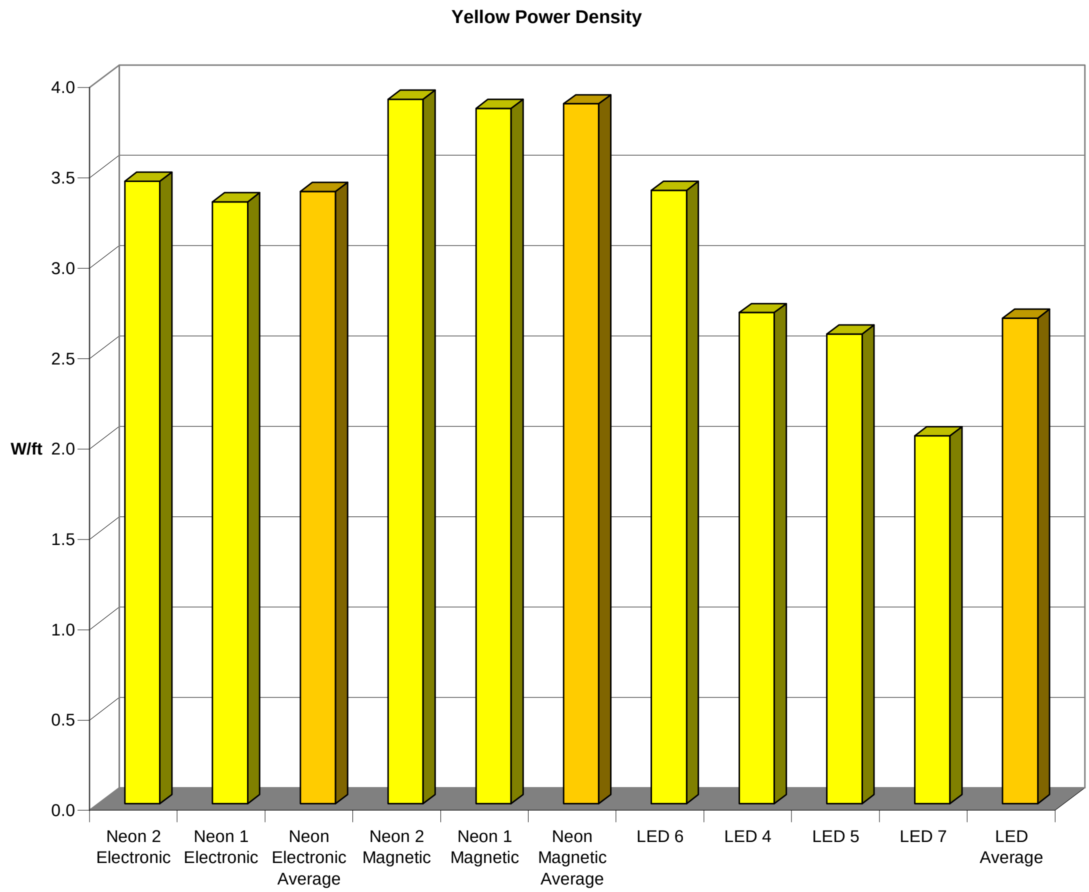



**FIGURE 13. YELLOW POWER DENSITY**

In general, for all colors, the average power density for the LED products was approximately 26% lower than the electronic neon and approximately 44% lower than the magnetic neon.

## LUMINANCE

Luminance data was read directly from the corresponding meter, as described in the Technical Approach section. The following graphs show the luminance for each color and each manufacturer. Data was grouped by technology and then sorted within each technology from highest to lowest.

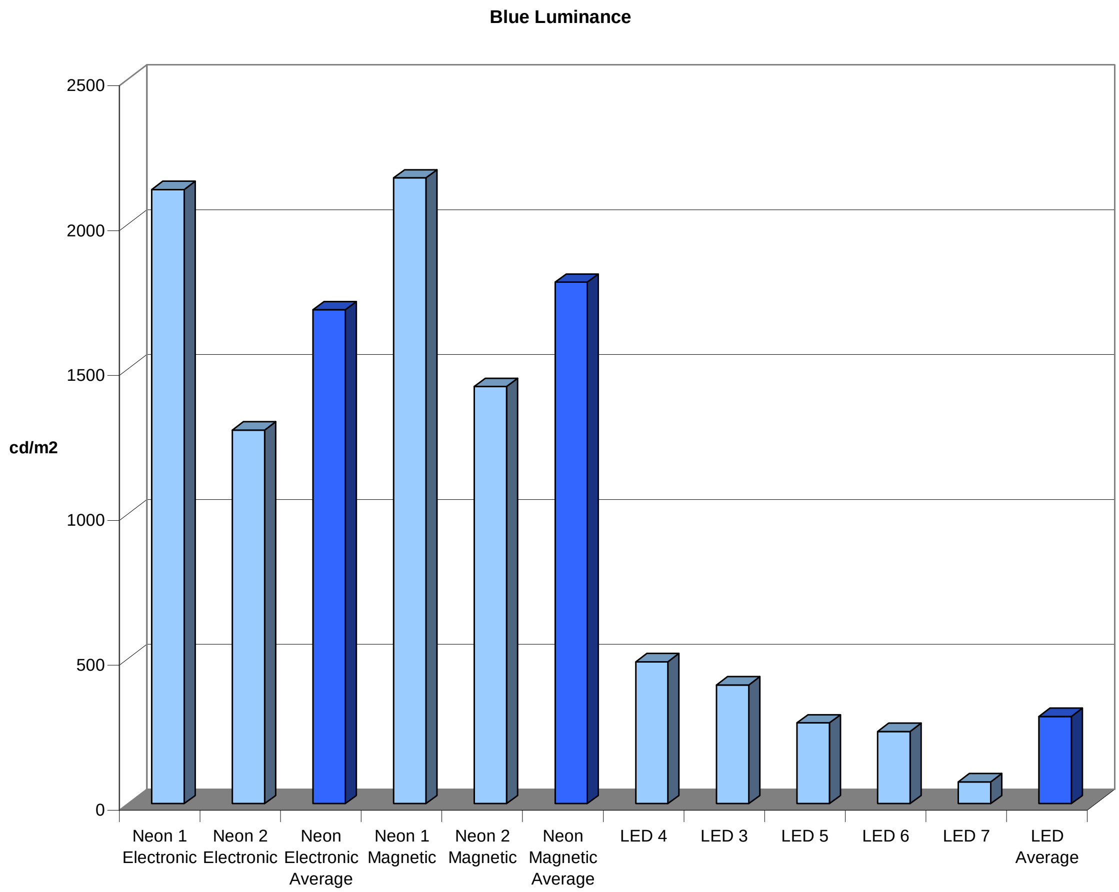



**FIGURE 14. BLUE LUMINANCE**

For blue, the average luminance for the LED products was 466% lower than the electronic neon and 498% lower than the magnetic neon.

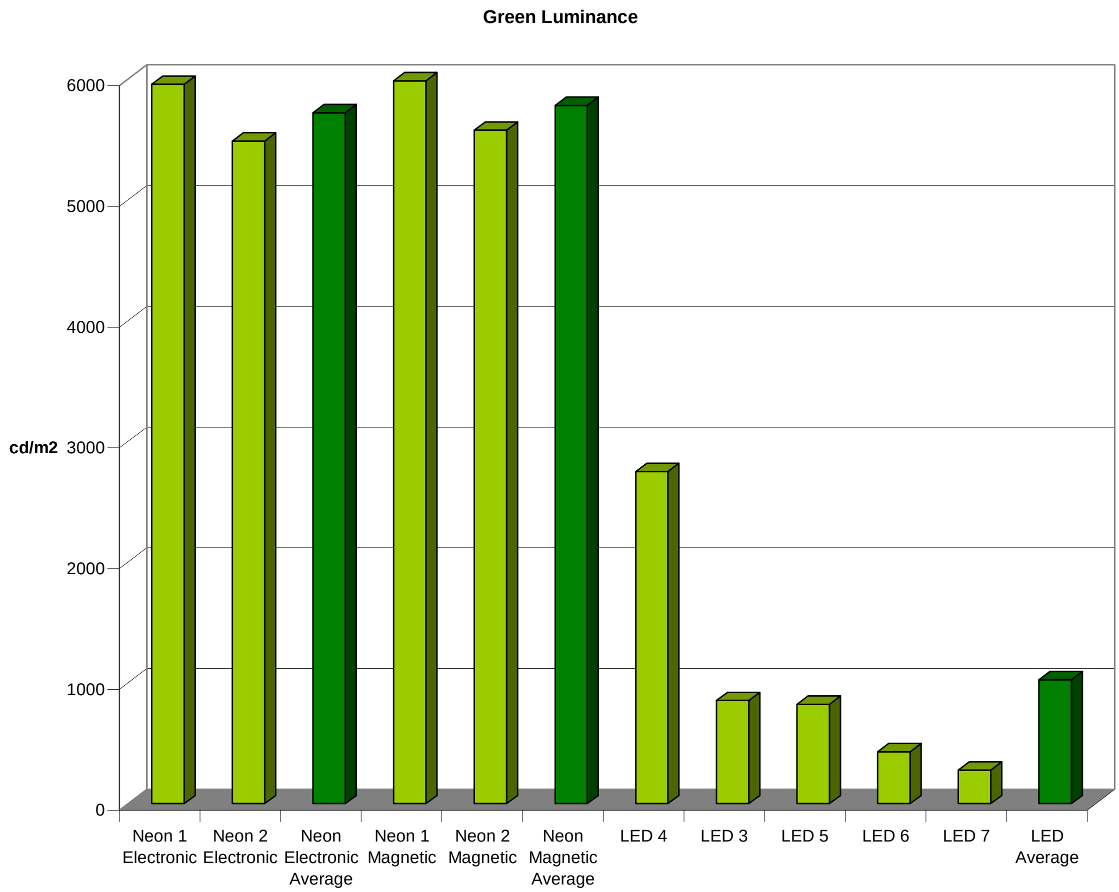



**FIGURE 15. GREEN LUMINANCE**

For green, the average luminance for the LED products was 460% lower than the electronic neon and 463% lower than the magnetic neon.

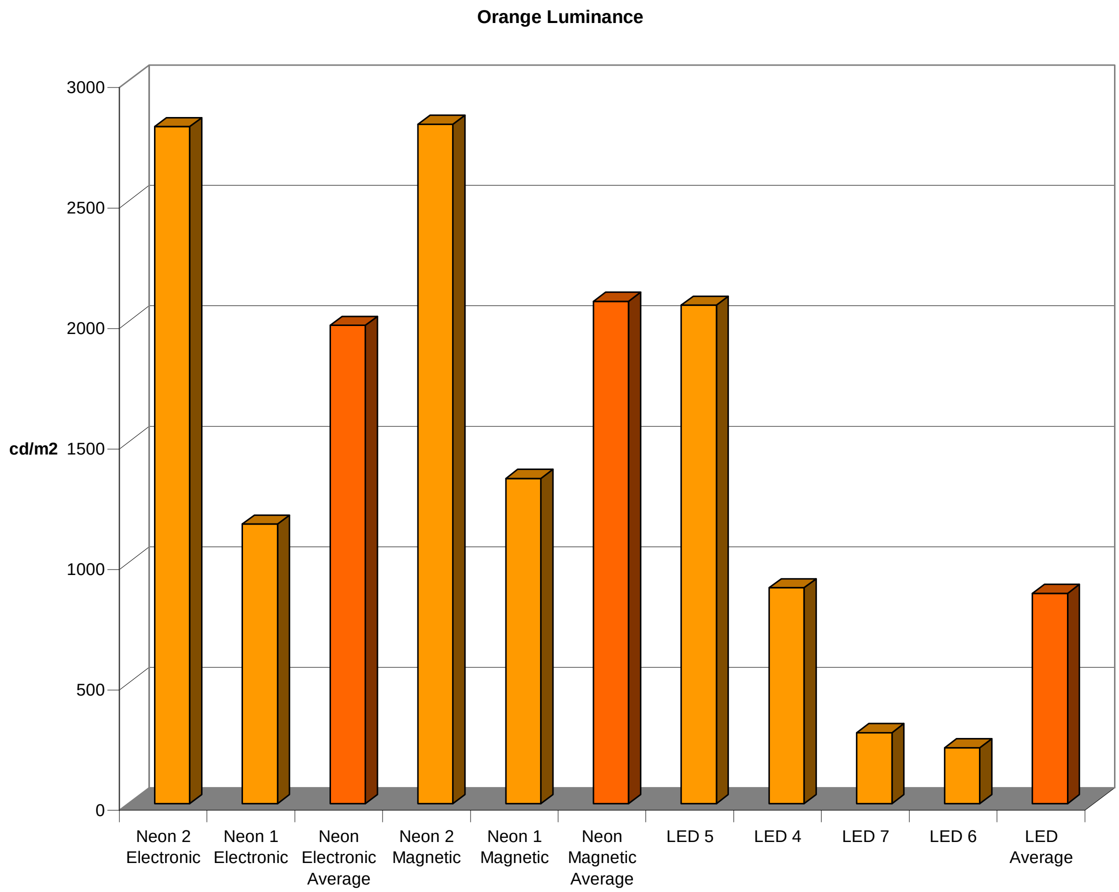



**FIGURE 16. ORANGE LUMINANCE**

For orange, the average luminance for the LED products was 127% lower than the electronic neon and 139% lower than the magnetic neon.

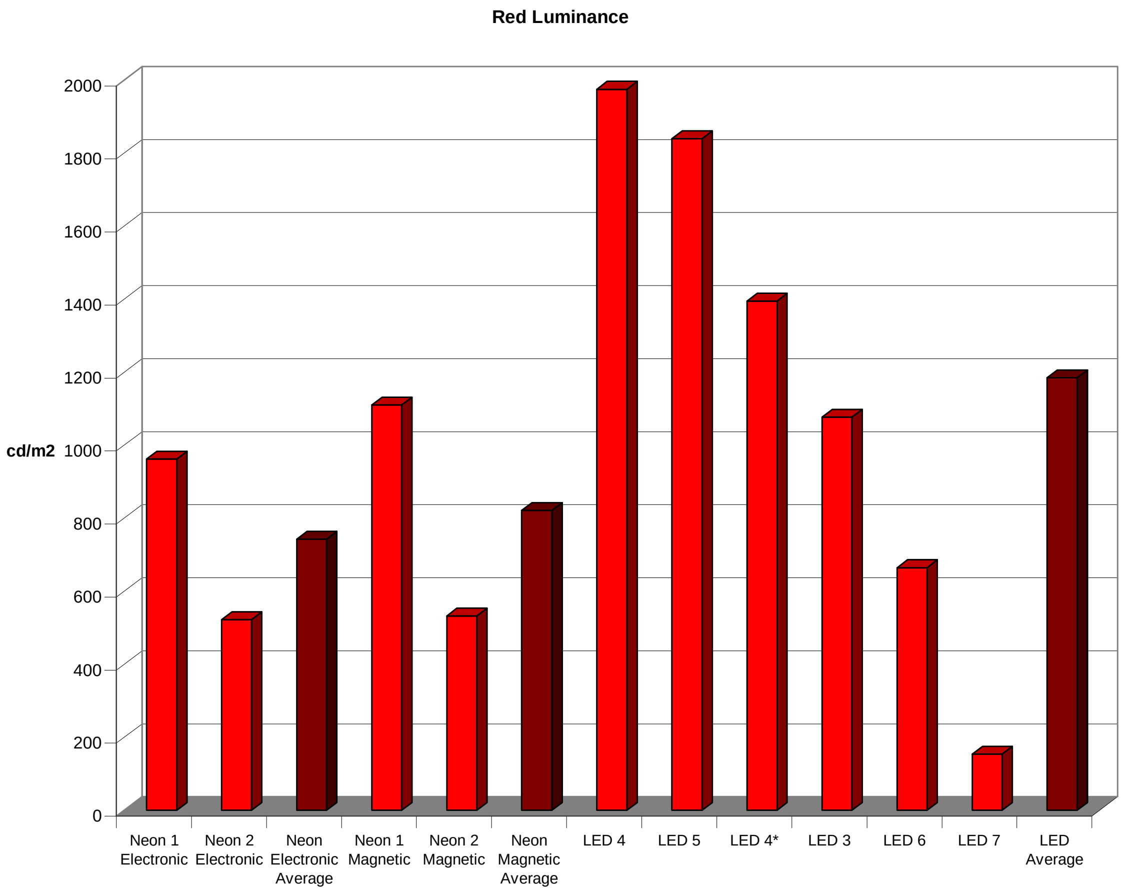



**FIGURE 17. RED LUMINANCE**

For red, the average luminance for the LED products was 59% higher than the electronic neon and 44% higher than the magnetic neon.

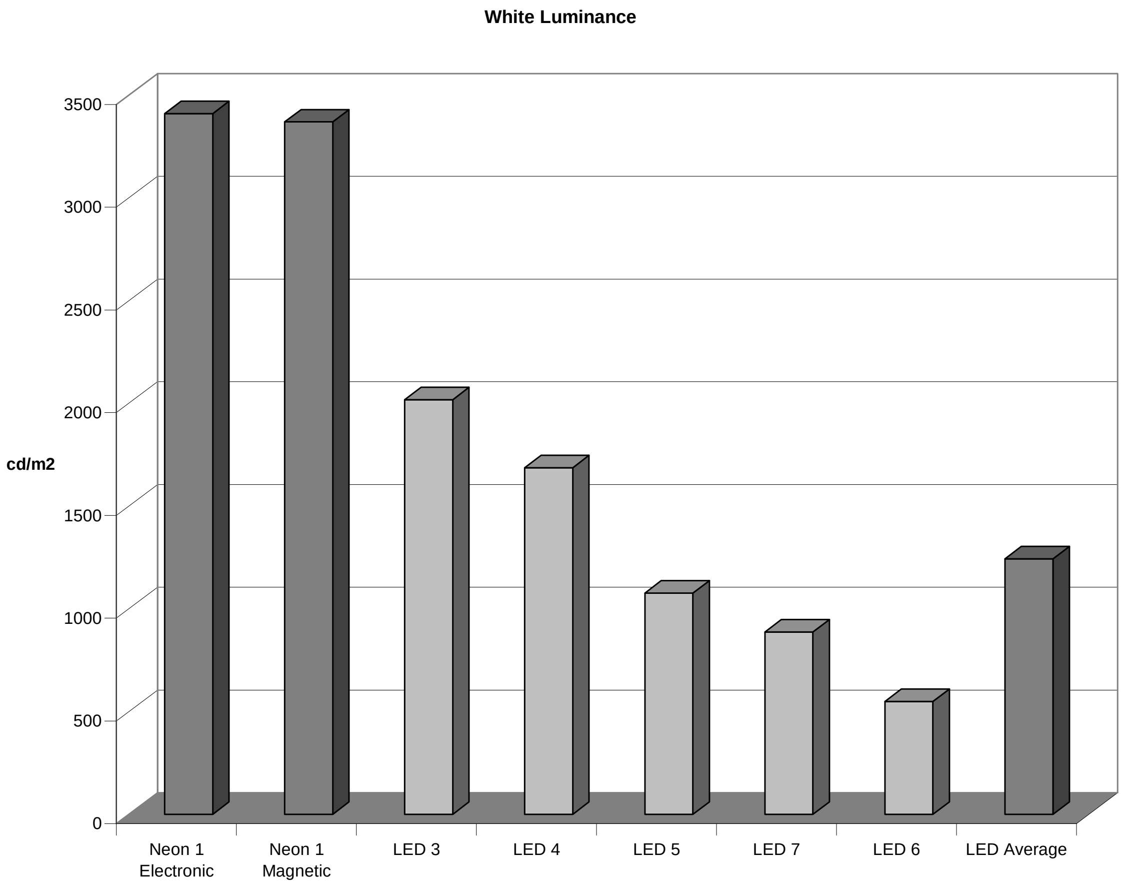



**FIGURE 18. WHITE LUMINANCE.**

For white, the average luminance for the LED products was 174% lower than the electronic neon and 171% lower than the magnetic neon.

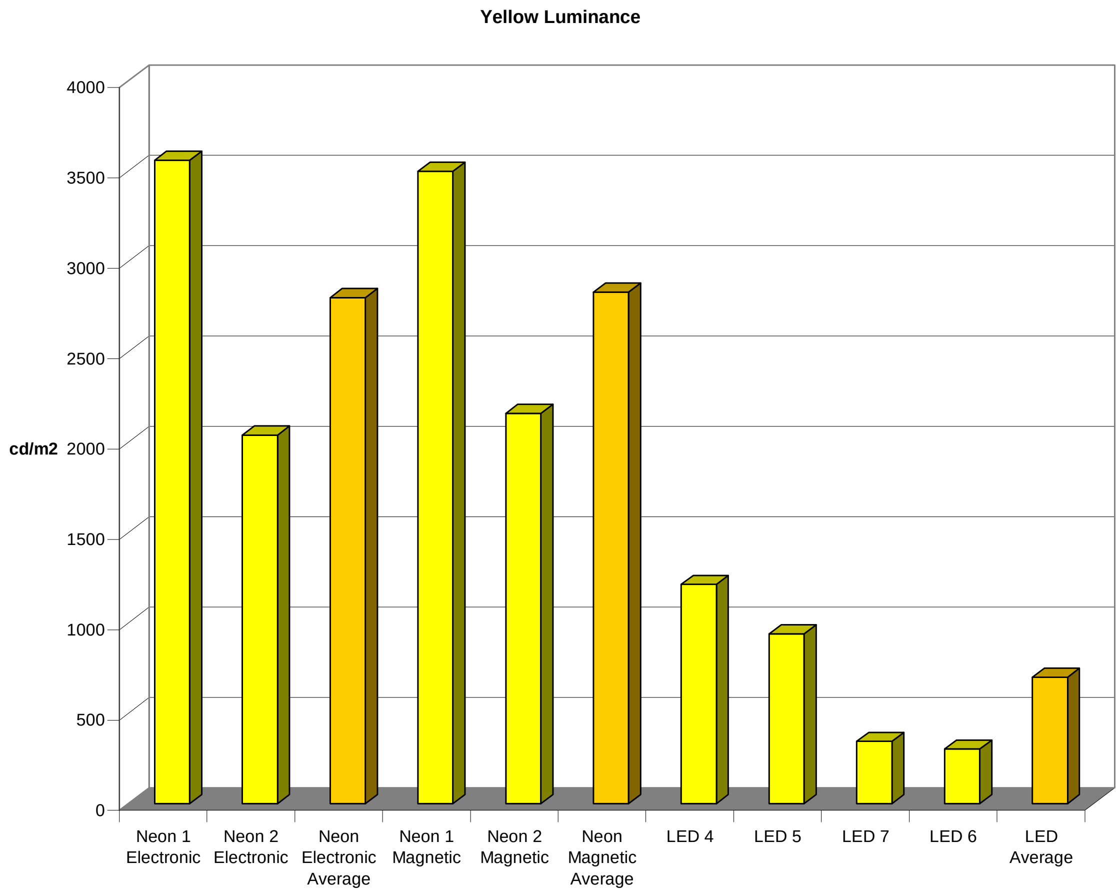



FIGURE 19. YELLOW LUMINANCE

For yellow, the average luminance for the LED products was 300% lower than the electronic neon and 304% lower than the magnetic neon.

# EFFICIENCY

Efficiency (ratio of luminance to power density; candelas per square meter per watts per foot, or candela-feet per square meter-watts) was calculated by taking the luminance and dividing it by the power density for each product. For example, the efficiency of Neon 1 Electronic Blue was calculated using the formula shown in Equation 2.

EQUATION 2. EFFICIENCY FOR NEON 1 ELECTRONIC BLUE

$$Efficacy = \frac{Luminance}{PowerDensity} = \frac{2{,}120 CandelasPerSquareMeter}{3.3 WattsPerFoot} = 642$$

The following graphs illustrate the efficiency for each color and each manufacturer. Data is grouped by technology and sorted within each technology from highest to lowest.

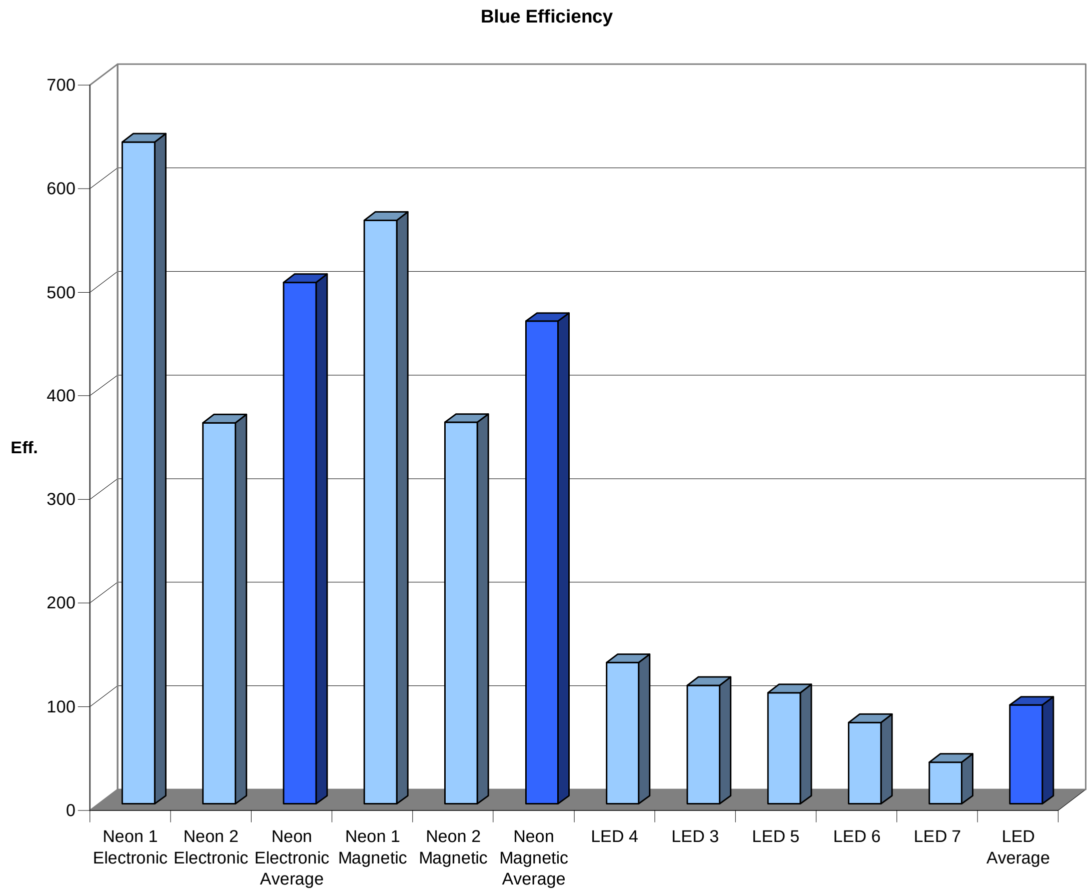



**FIGURE 20. BLUE EFFICIENCY**

For blue, the average efficiency for the LED products was 424% lower than the electronic neon and 385% lower than the magnetic neon.

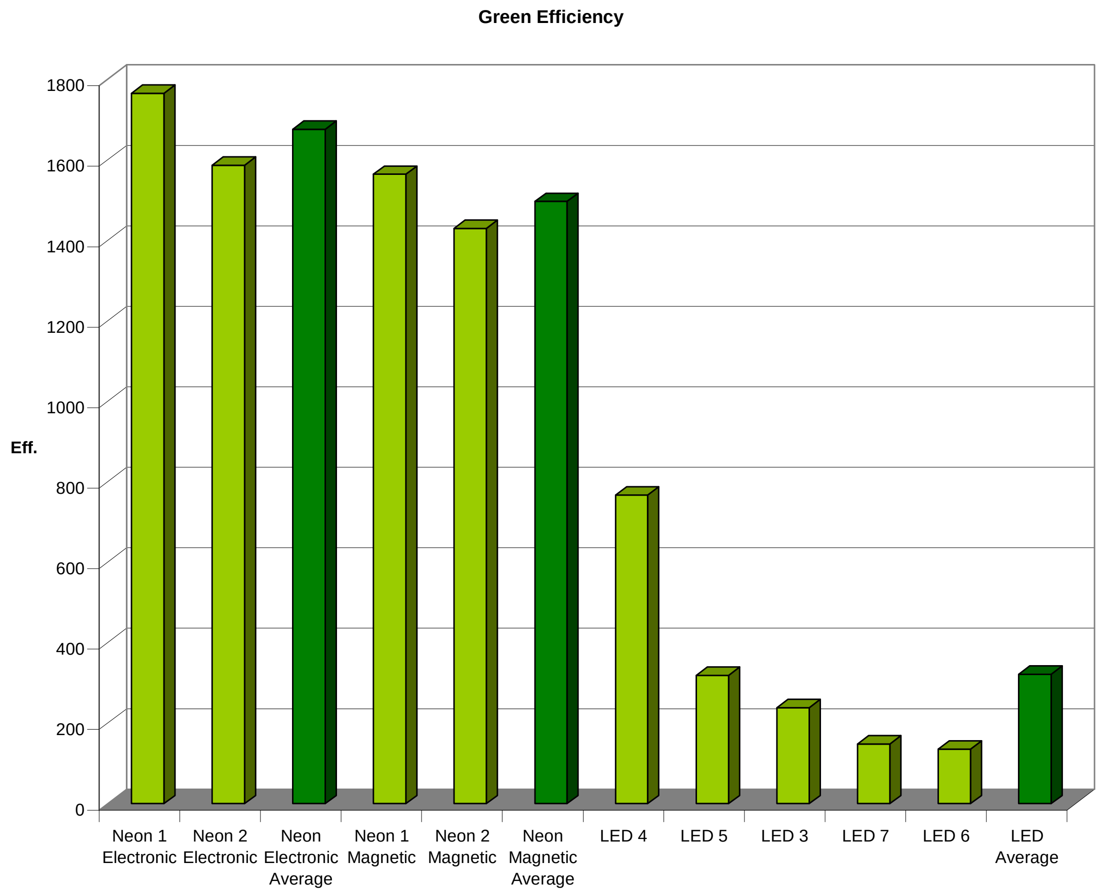



FIGURE 21. GREEN EFFICIENCY

For green, the average efficiency for the LED products was 420% lower than the electronic neon and 365% lower than the magnetic neon.

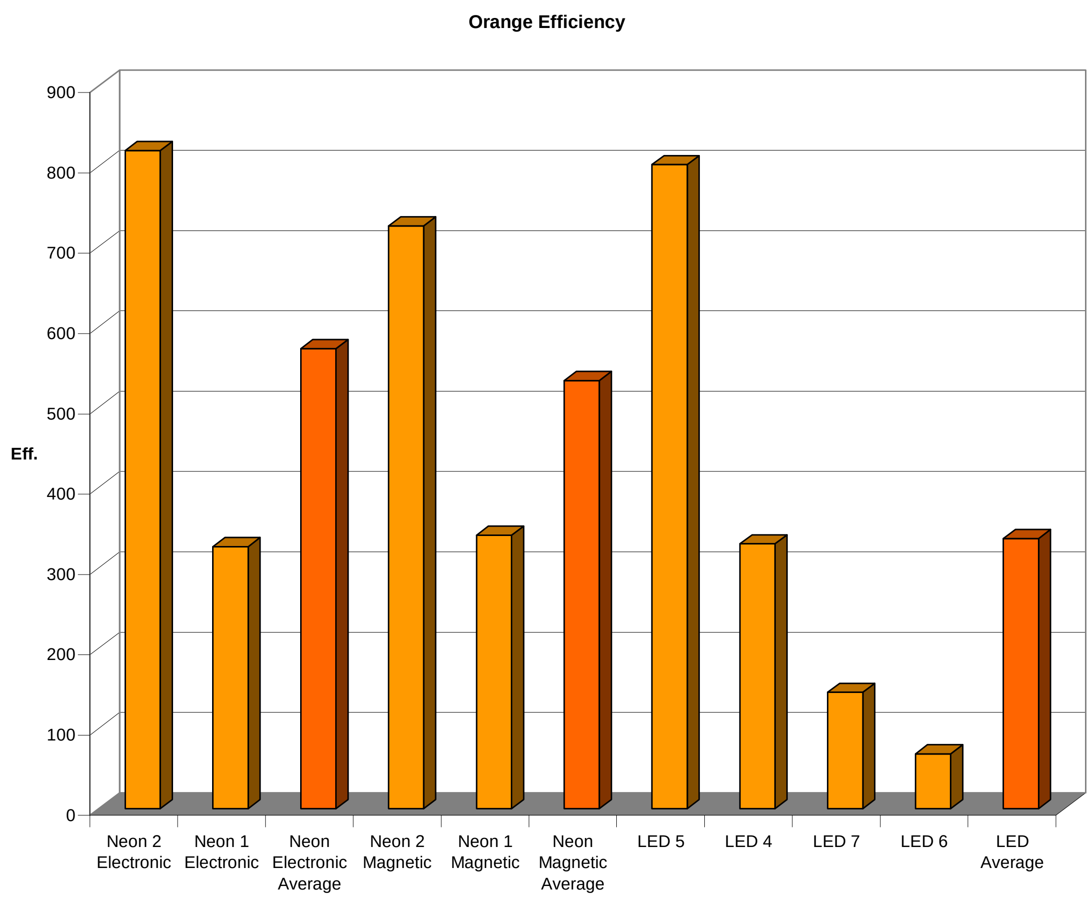



**FIGURE 22. ORANGE EFFICIENCY**

For orange, the average efficiency for the LED products was 71% lower than the electronic neon and 59% lower than the magnetic neon.

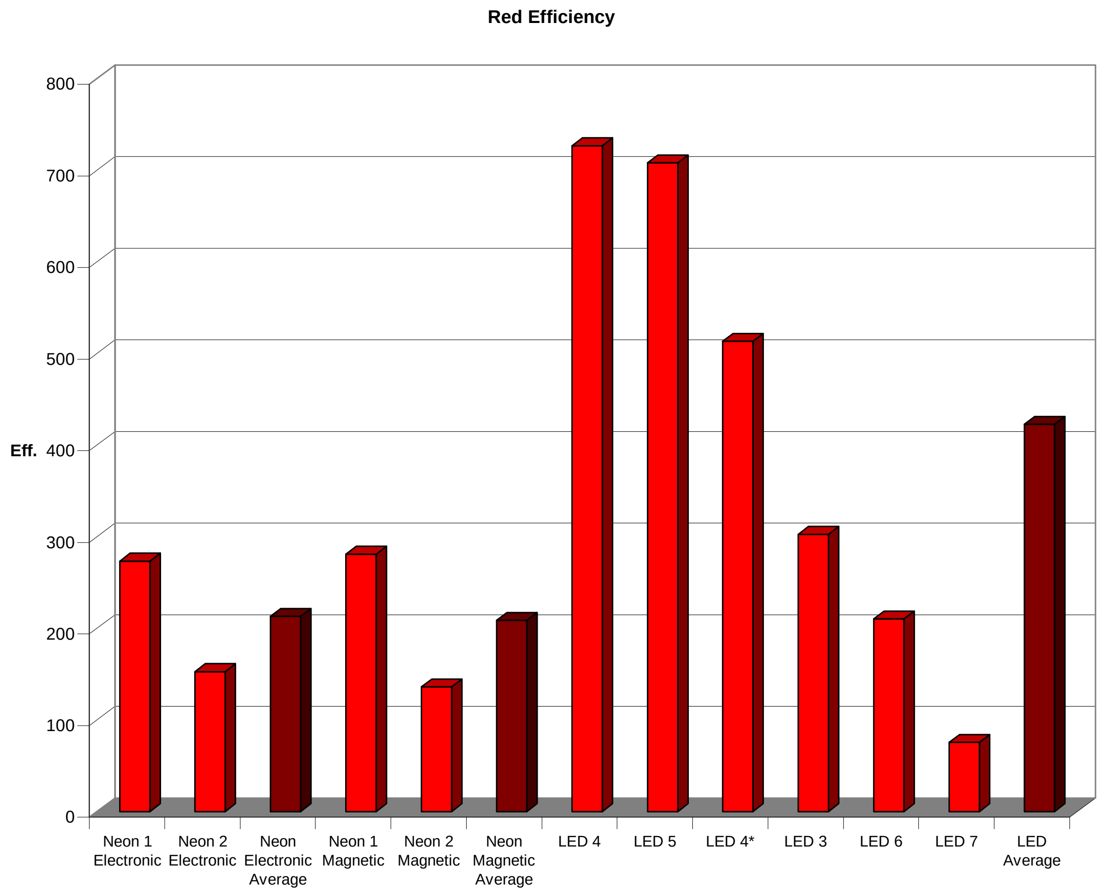



**FIGURE 23. RED EFFICIENCY**

For red, the average efficiency for the LED products was 99% higher than the electronic neon and 102% higher than the magnetic neon.

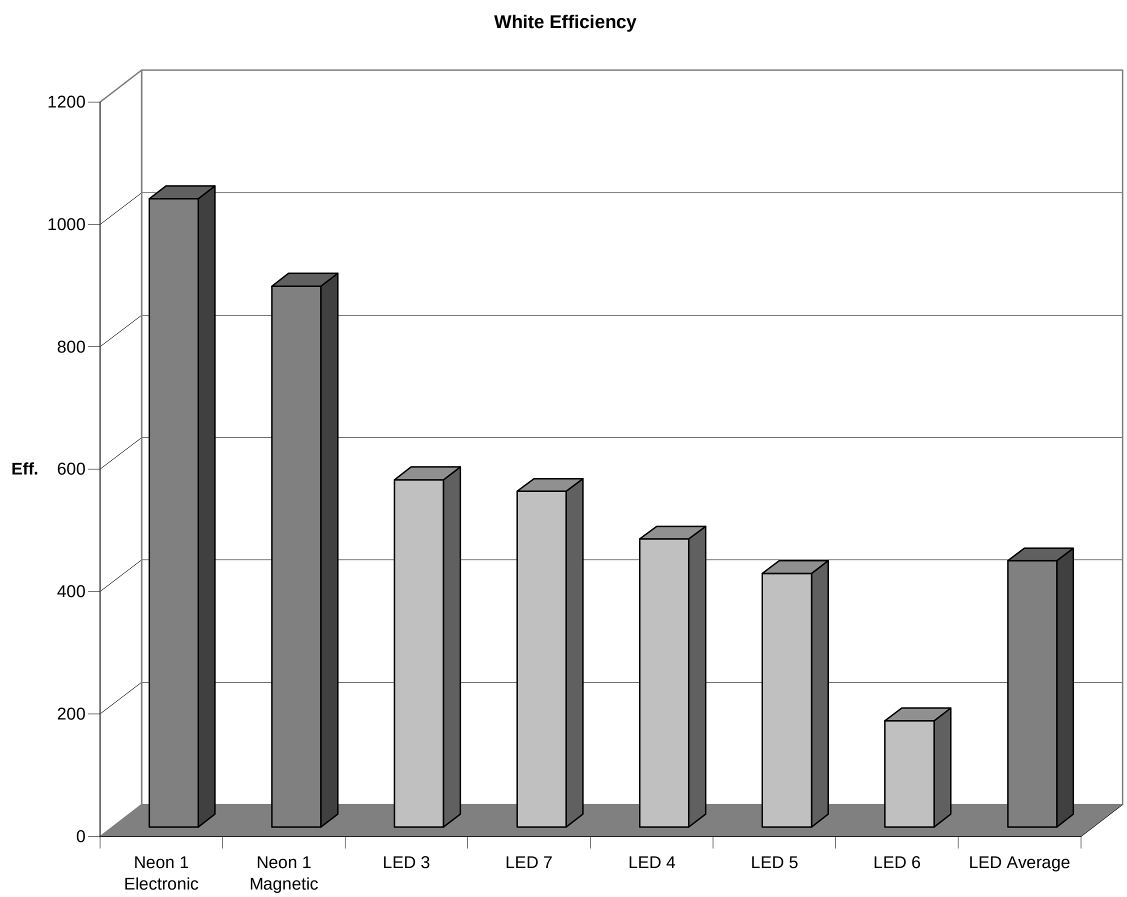



**FIGURE 24. WHITE EFFICIENCY**

For white, the average efficiency for the LED products was 136% lower than the electronic neon and 103% lower than the magnetic neon.

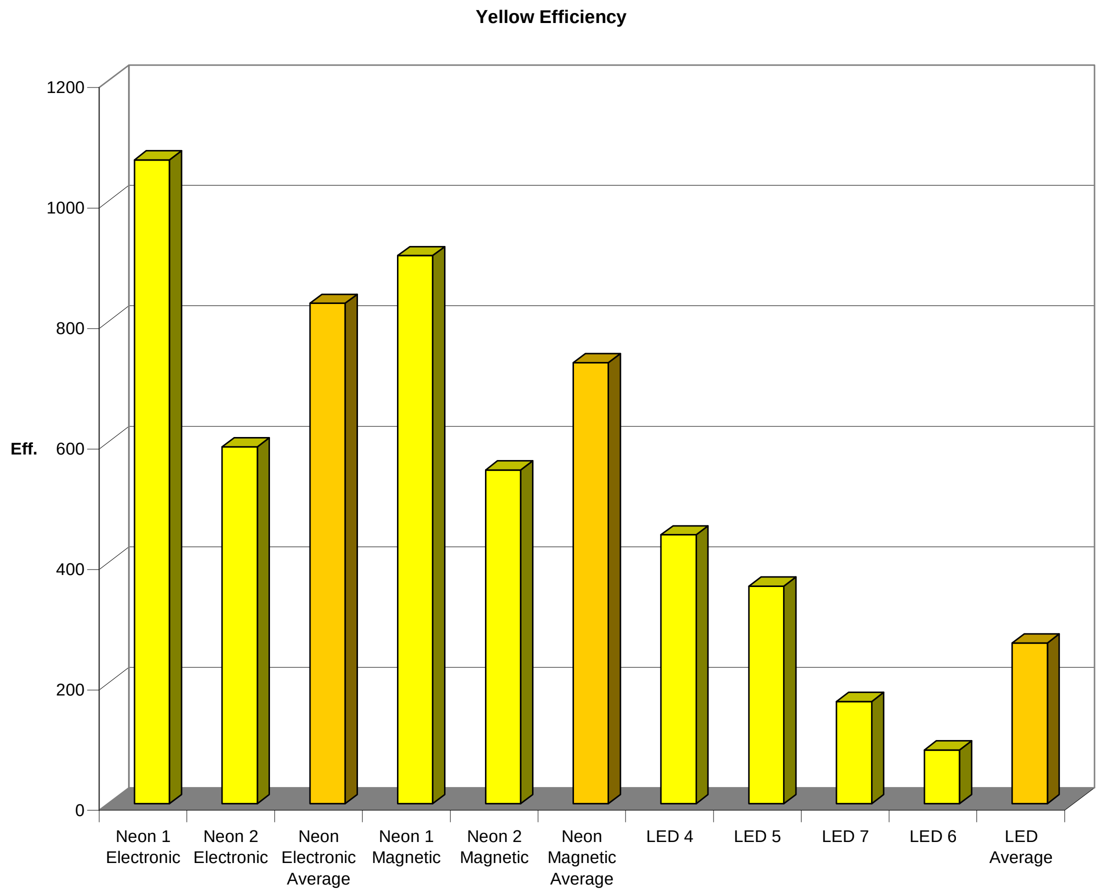



**FIGURE 25. YELLOW EFFICIENCY**

For yellow, the average efficiency for the LED products was 212% lower than the electronic neon and 175% lower than the magnetic neon.

# POWER FACTOR

Power factor, the ratio of real power to apparent power, was calculated by taking the average of the 29$^{th}$ minute of power factor data for each product. The following graphs show the power factor for each color and each manufacturer. Data is grouped by technology and sorted within each technology from highest to lowest.

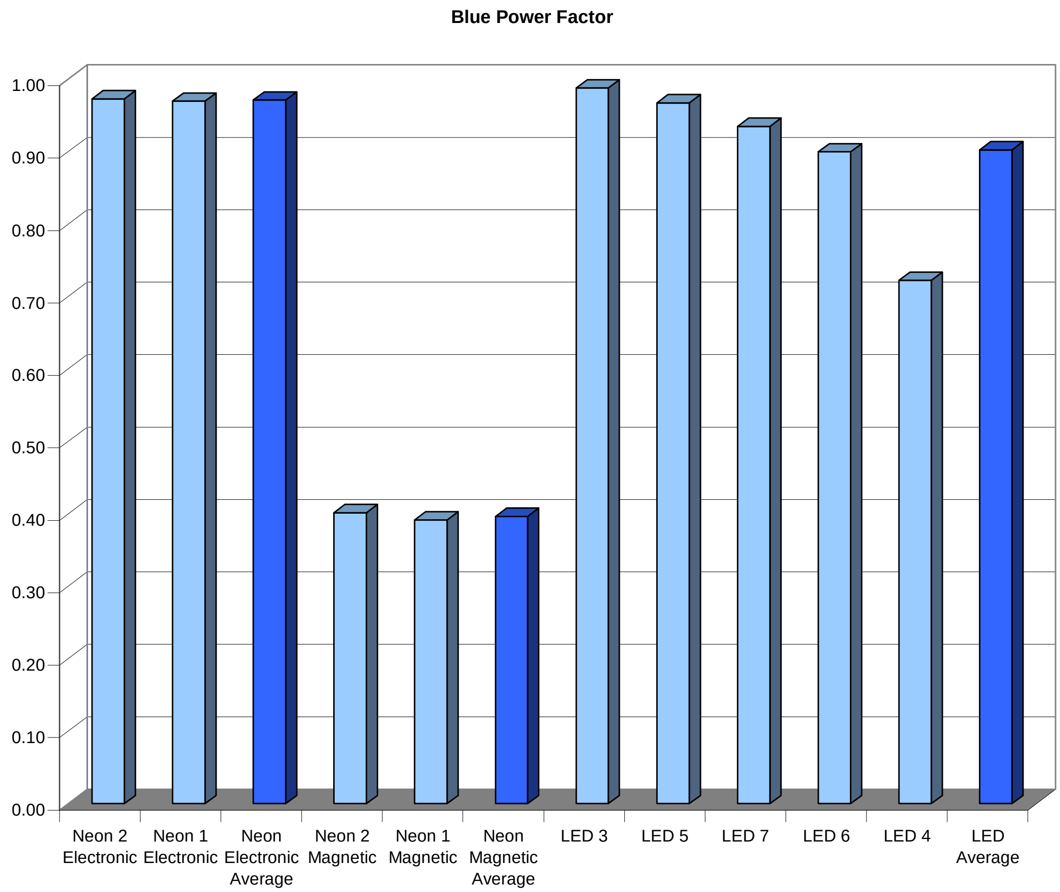



**FIGURE 26. BLUE POWER FACTOR**

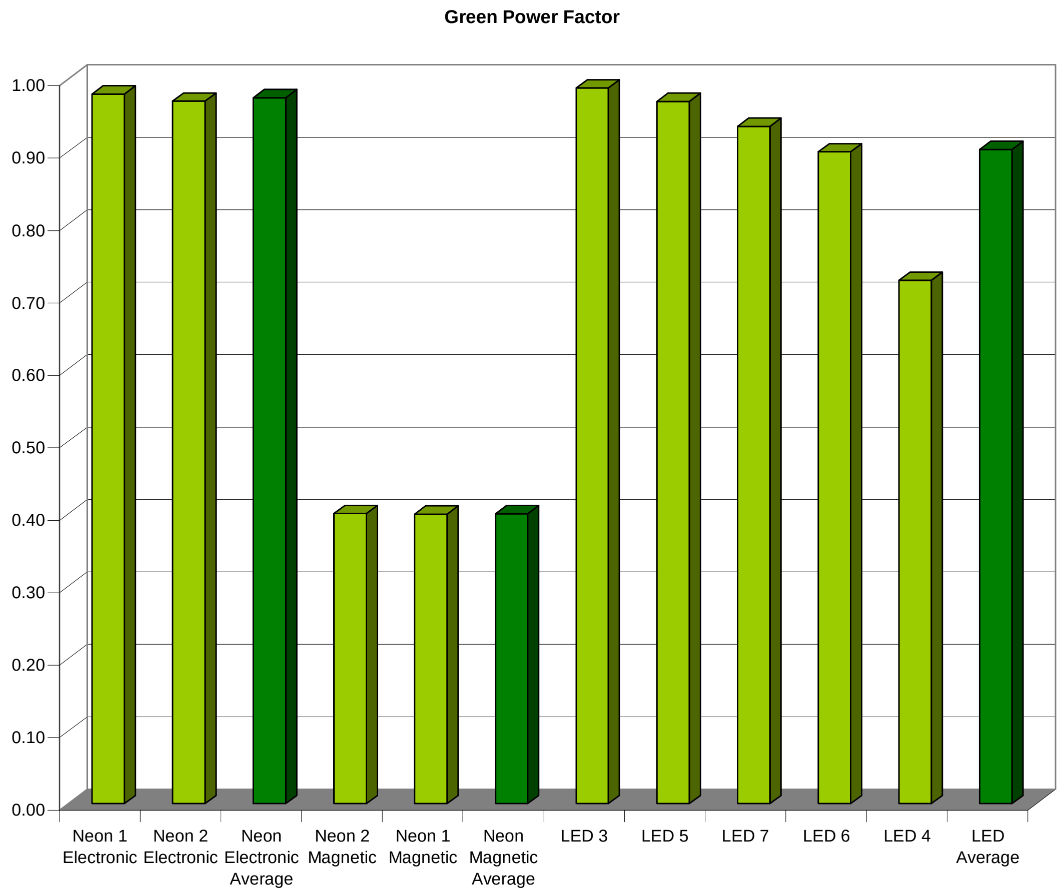



FIGURE 27. GREEN POWER FACTOR

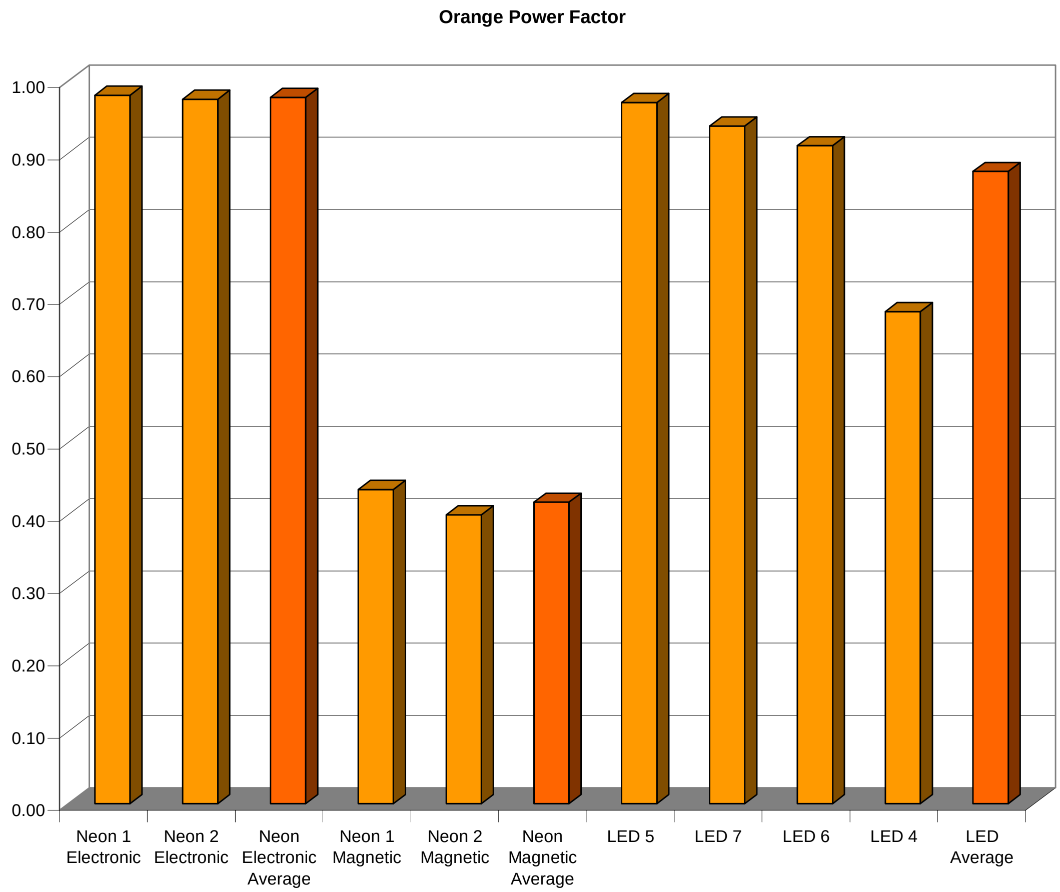



**FIGURE 28. ORANGE POWER FACTOR**

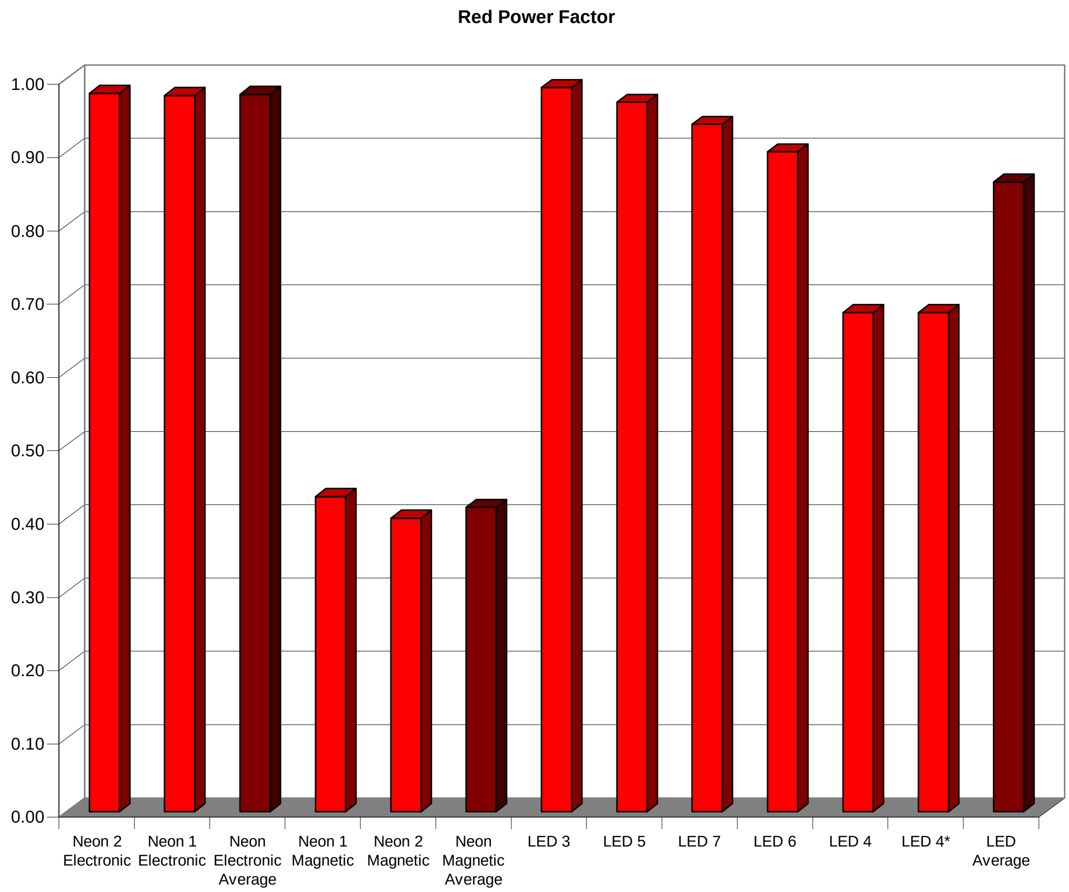



FIGURE 29. RED POWER FACTOR

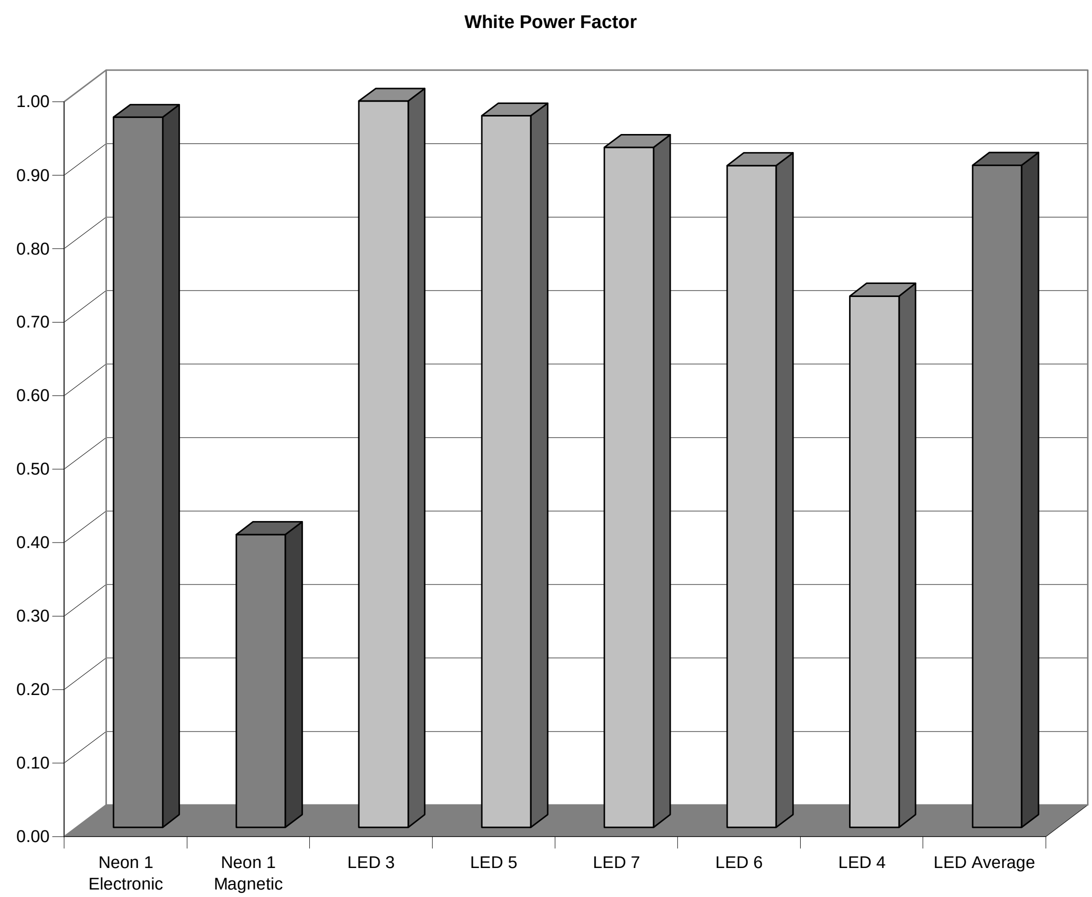



**FIGURE 30. WHITE POWER FACTOR**

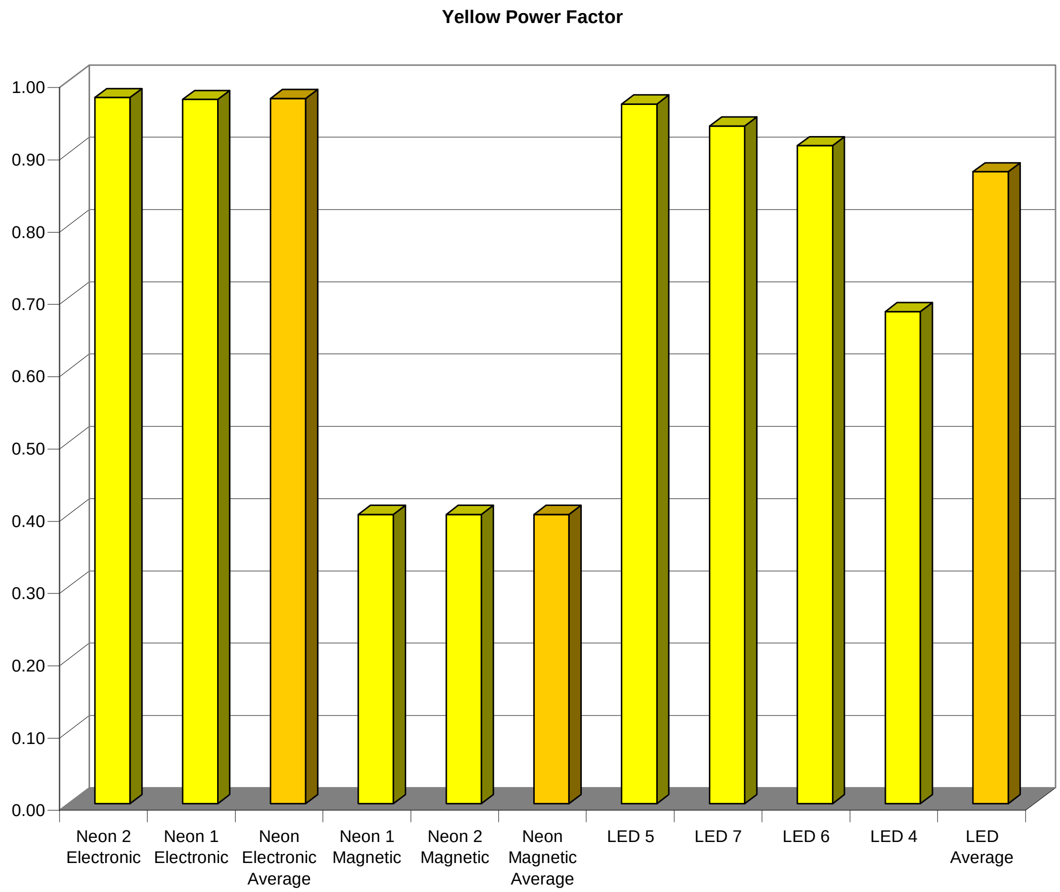



**FIGURE 31. YELLOW POWER FACTOR**

In general, for all colors, the average power factor for the LED products was approximately 13% lower than the electronic neon and approximately 118% higher than the magnetic neon.

## CURRENT THD

Current THD (percent current THD) was calculated by taking the average of the 29th minute of current THD data for each product. The following graphs show the current THD for each color and each manufacturer. Data is grouped by technology and sorted within each technology from highest to lowest.

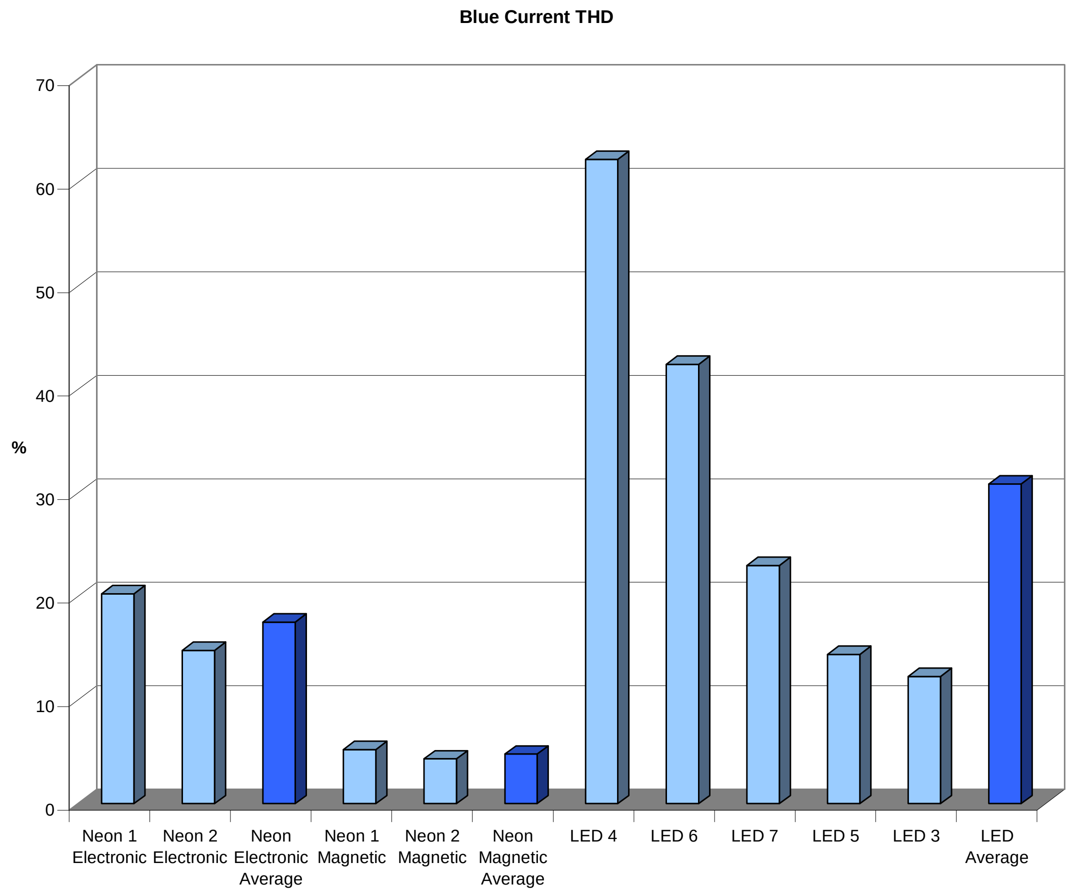



FIGURE 32. BLUE CURRENT THD

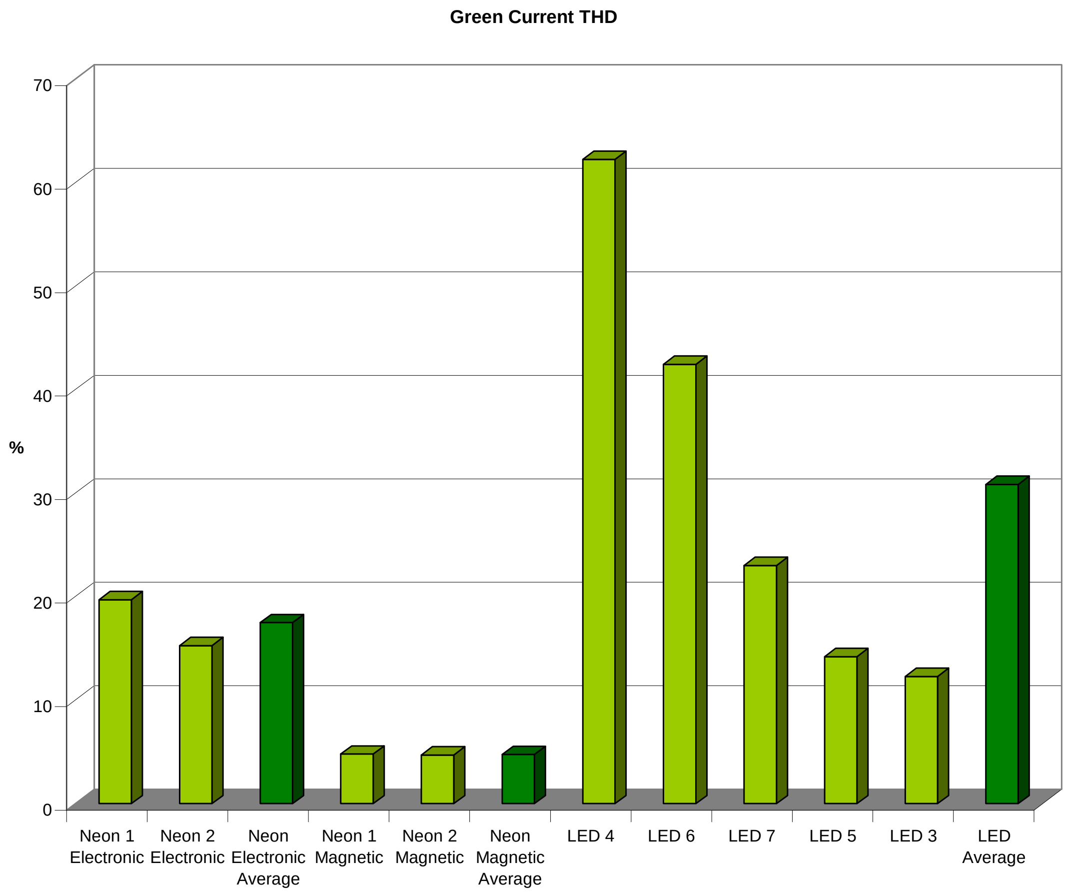



FIGURE 33. GREEN CURRENT THD

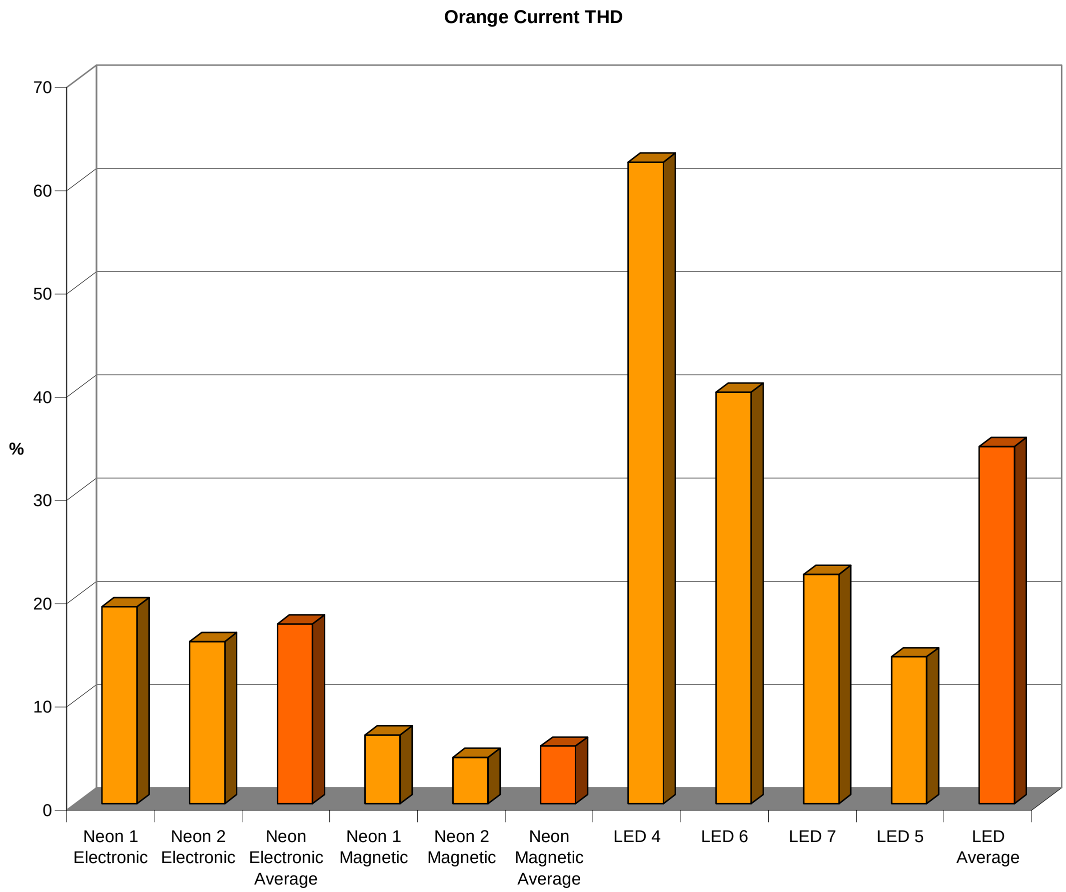



FIGURE 34. ORANGE CURRENT THD

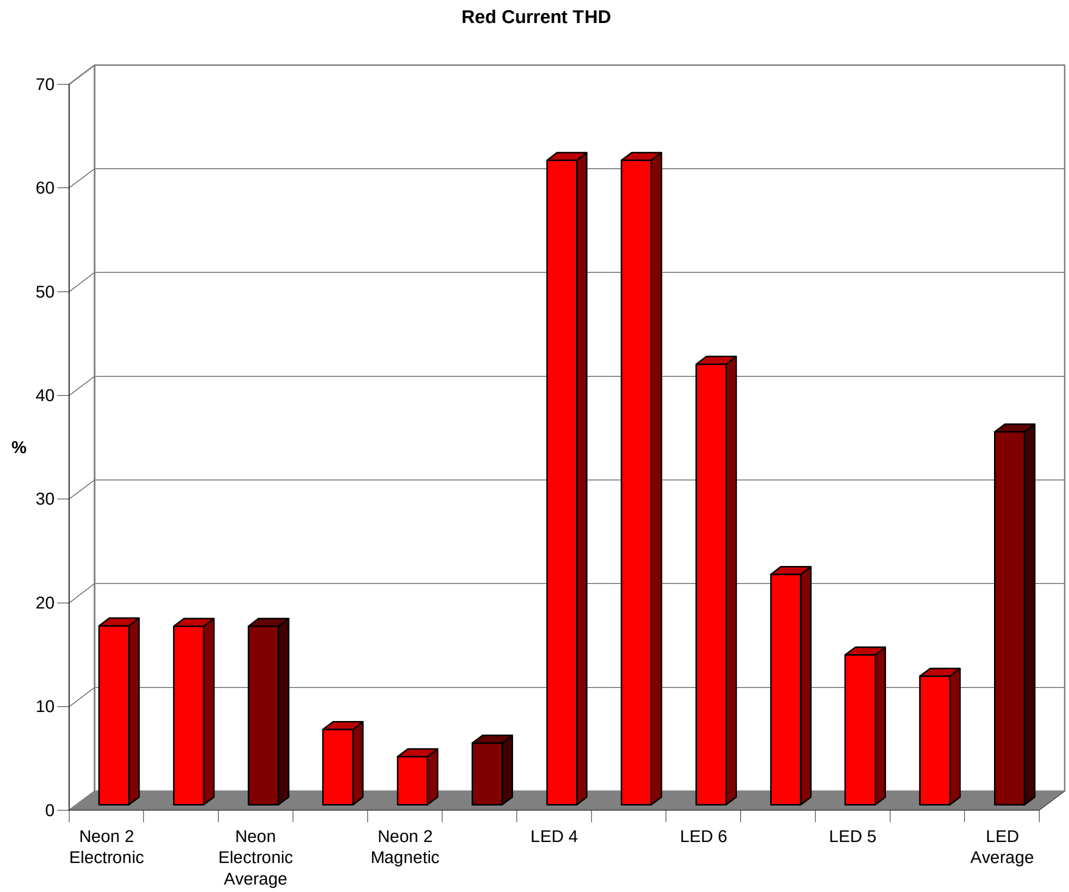



**FIGURE 35. RED CURRENT THD**

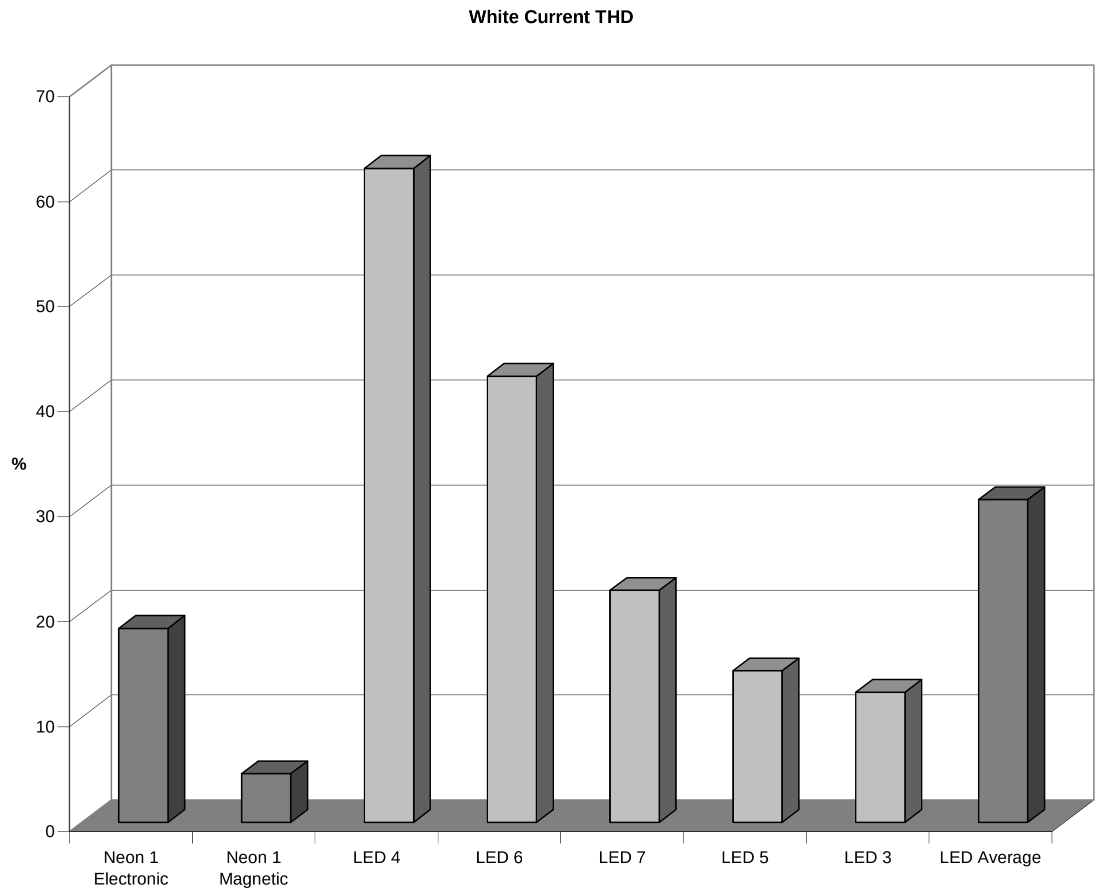



**FIGURE 36. WHITE CURRENT THD**

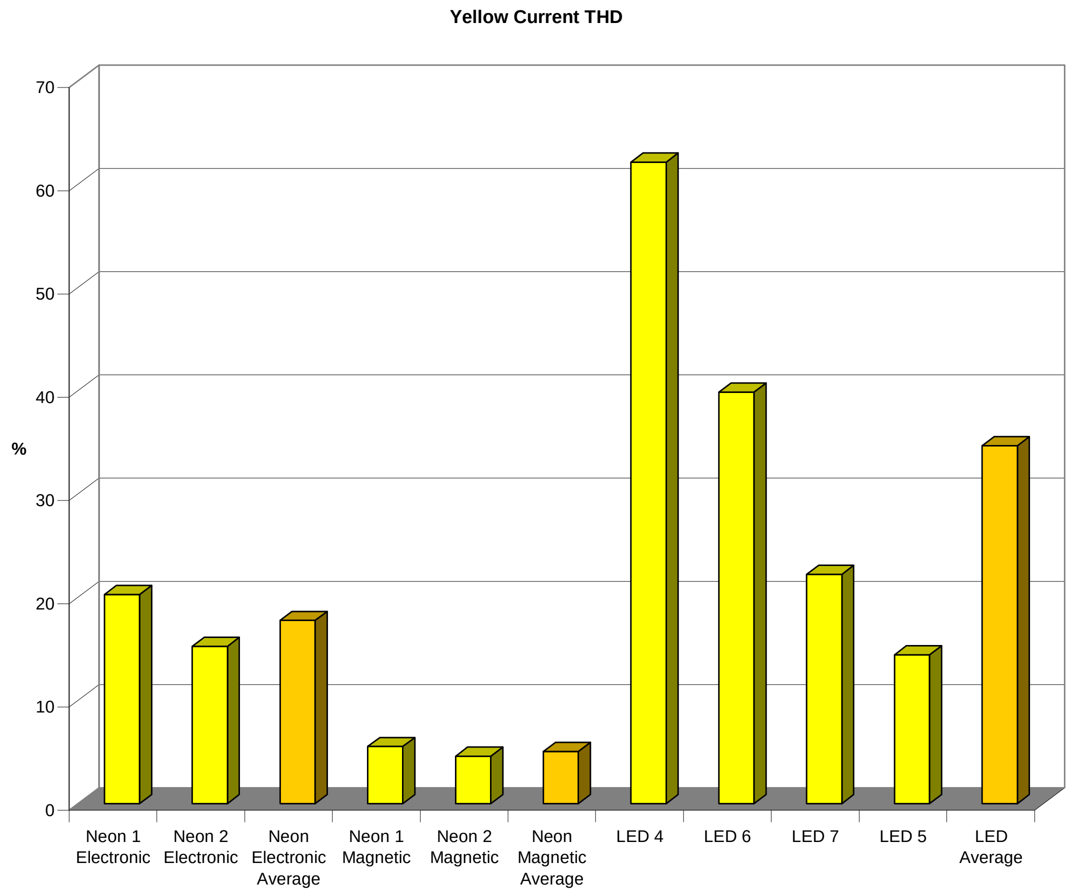



**FIGURE 37. YELLOW CURRENT THD**

In general, for all colors, the average current THD for the LED products was approximately 94% higher than the electronic neon and approximately 600% higher than the magnetic neon.

# COLOR

Color data was read directly from the chroma meter, as described in the Technical Approach section. Distances between each technology of the same color were calculated using the distance formula. For example, the distance between Green LED Average and Green Neon Average was calculated using the formula in Equation 3.

**EQUATION 3. DISTANCE BETWEEN GREEN LED AND GREEN NEON**

$$Distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} = \sqrt{(.21 - .176)^2 + (.604 - .711)^2} = 0.112$$

Table 10 shows the distance between each color of the same technology.

**TABLE 10. DISTANCES BETWEEN TECHNOLOGIES OF THE SAME COLOR**

| Color | Distance | Relatively Close to Neon | More Pure |
|---|---|---|---|
| Blue | 0.096 | No | LED |
| Green | 0.112 | No | LED |
| Orange | 0.019 | Yes | N/A |
| Red | 0.004 | Yes | N/A |
| White | 0.026 | Yes | N/A |
| Yellow | 0.114 | No | Neon |

The following CIE 1931 Chromaticity Diagram shows the average location for each color and each technology.

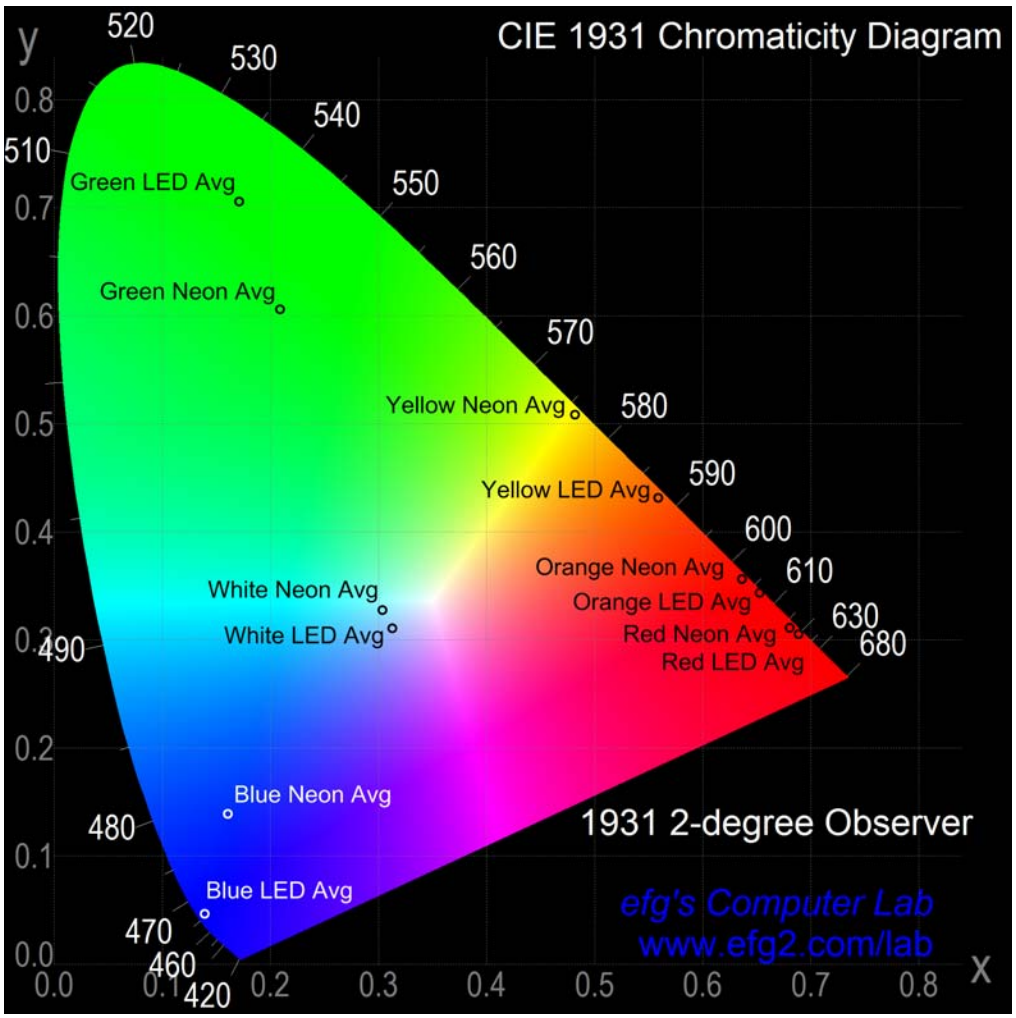
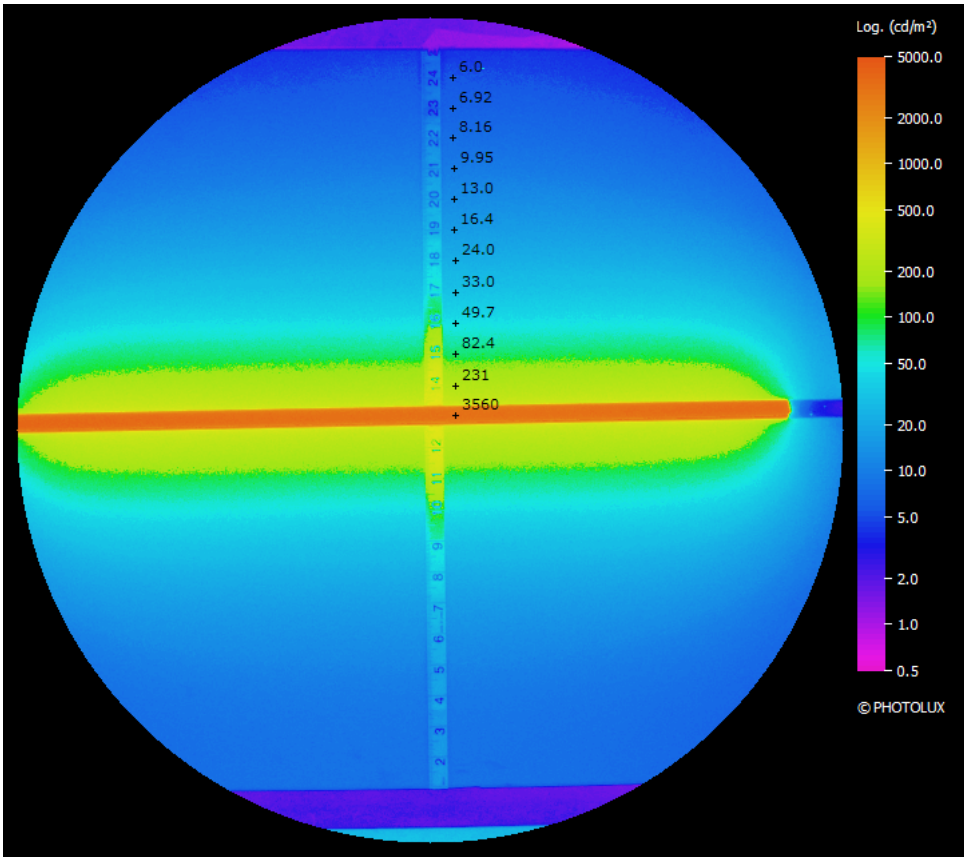



**FIGURE 38. AVERAGE COLOR LOCATIONS ON CHROMATICITY DIAGRAM. THE GRAY NUMBERS ALONG THE AXES CORRESPOND TO THE [X,Y] CHROMATICITY COORDINATES, WHILE THE WHITE NUMBERS ARE LIGHT WAVELENGTHS (IN NM) ALONG THE SPECTRAL LOCUS.**

# CONTRAST

Contrast was analyzed using the Photolux system. The pictures from the Technical Approach section were imported into Photolux, which created a false-color luminance map. Using tools in Photolux and the cloth measuring tape in the pictures as a reference, luminance values were labeled in 1-inch increments from the center of the product to the top of the test sign cabinet. The following figures are the luminance maps for all blue products. Below each luminance map is a graph showing the luminance value on a logarithmic scale.



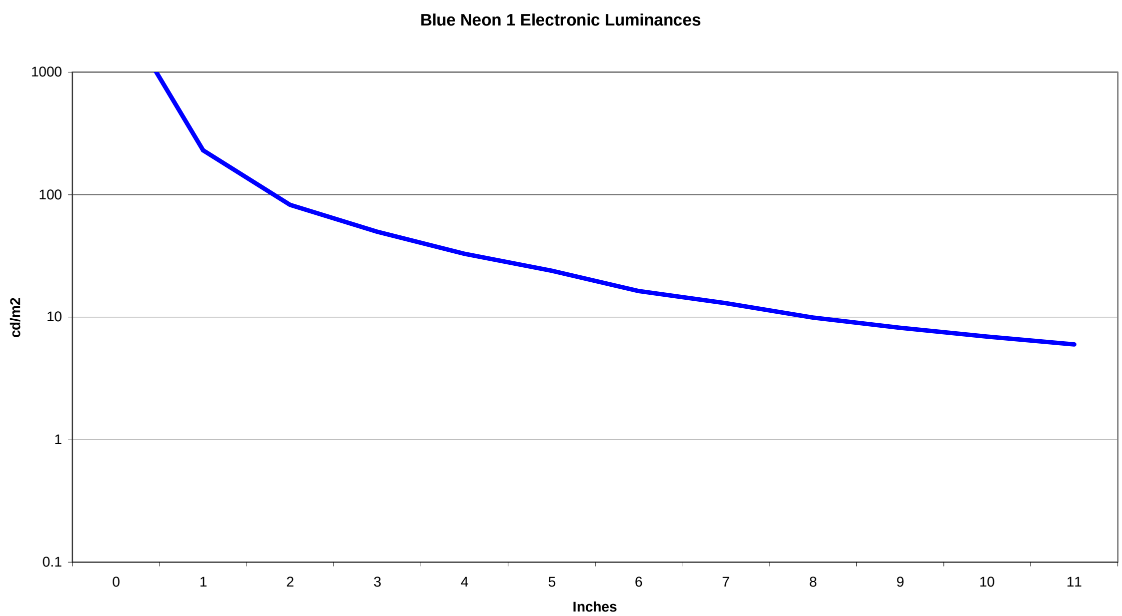
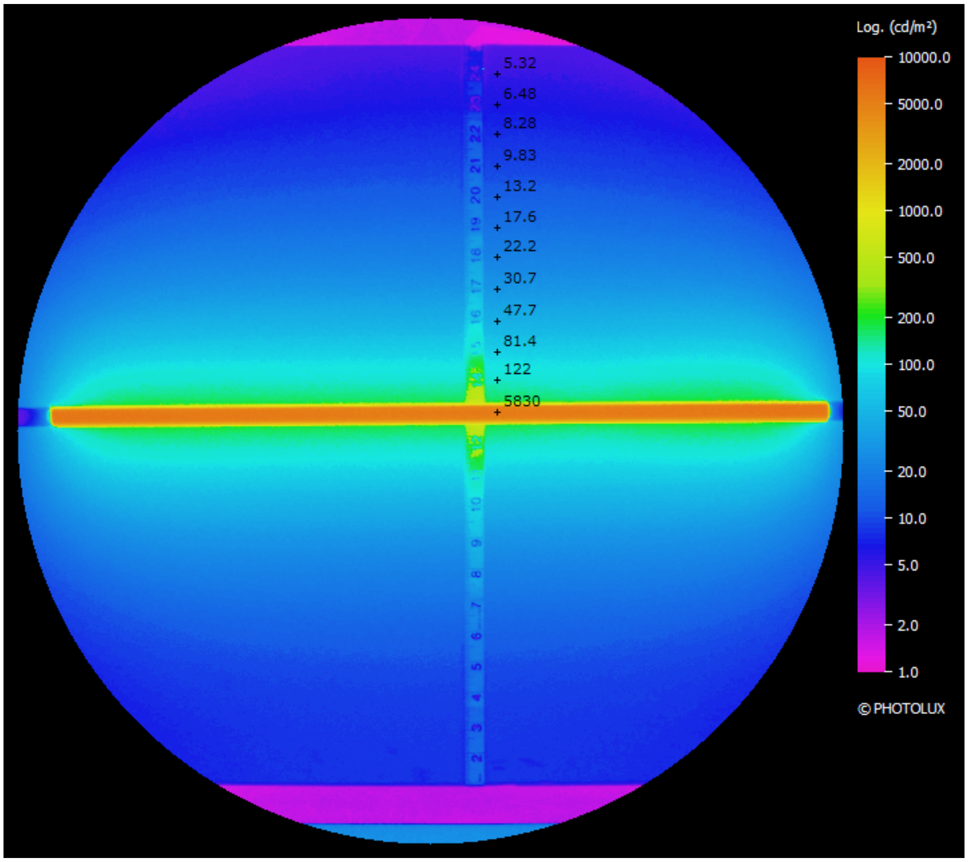




**FIGURE 39. BLUE NEON 1 ELECTRONIC LUMINANCE MAP AND GRAPH. THE LUMINANCE GRAPH IS RELATIVELY SMOOTH AND GRADUAL COMPARED TO THE LED PRODUCTS, INDICATING LOWER CONTRAST AND MORE BACKGROUND ILLUMINATION.**



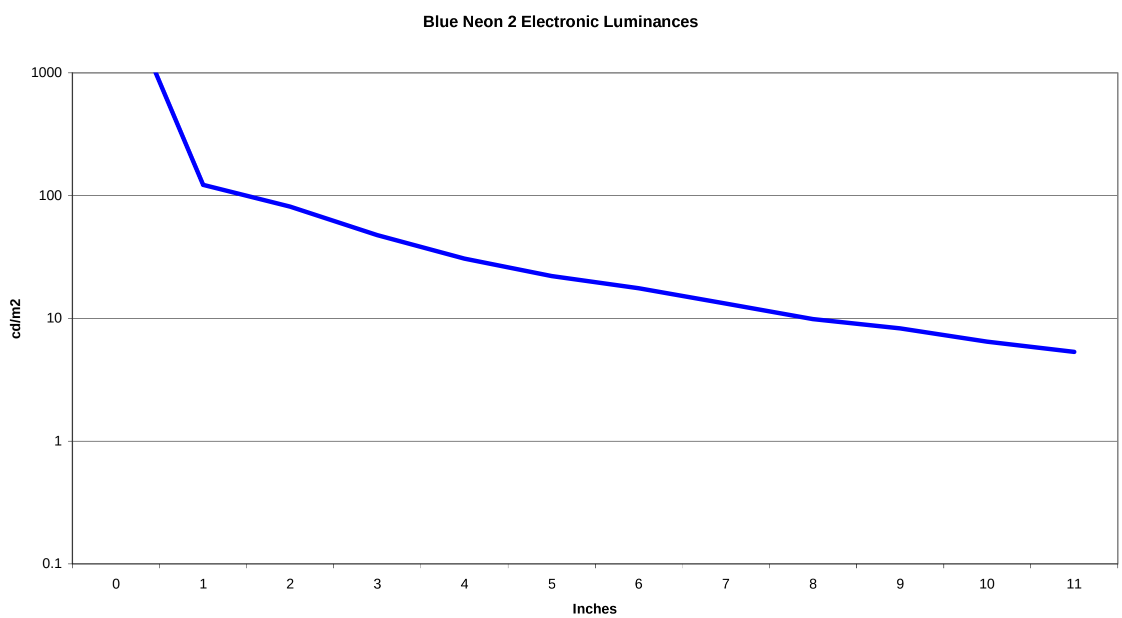
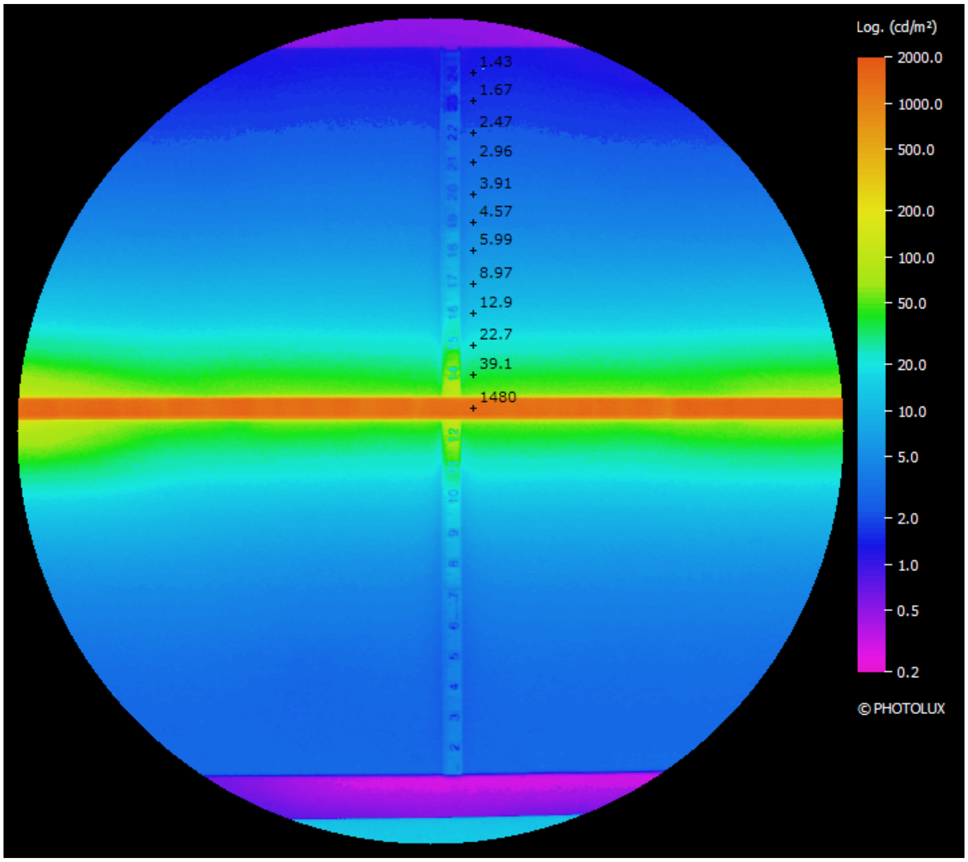




**Figure 40. Blue Neon 2 Electronic Luminance Map and Graph. The luminance graph is relatively smooth and gradual compared to the LED products, indicating lower contrast and more background illumination.**



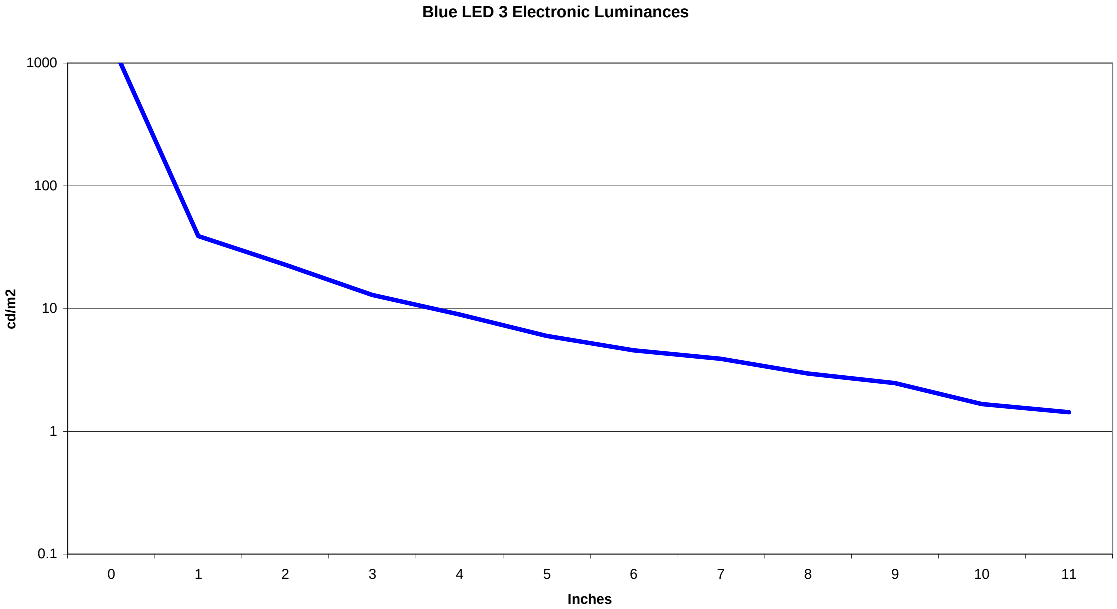
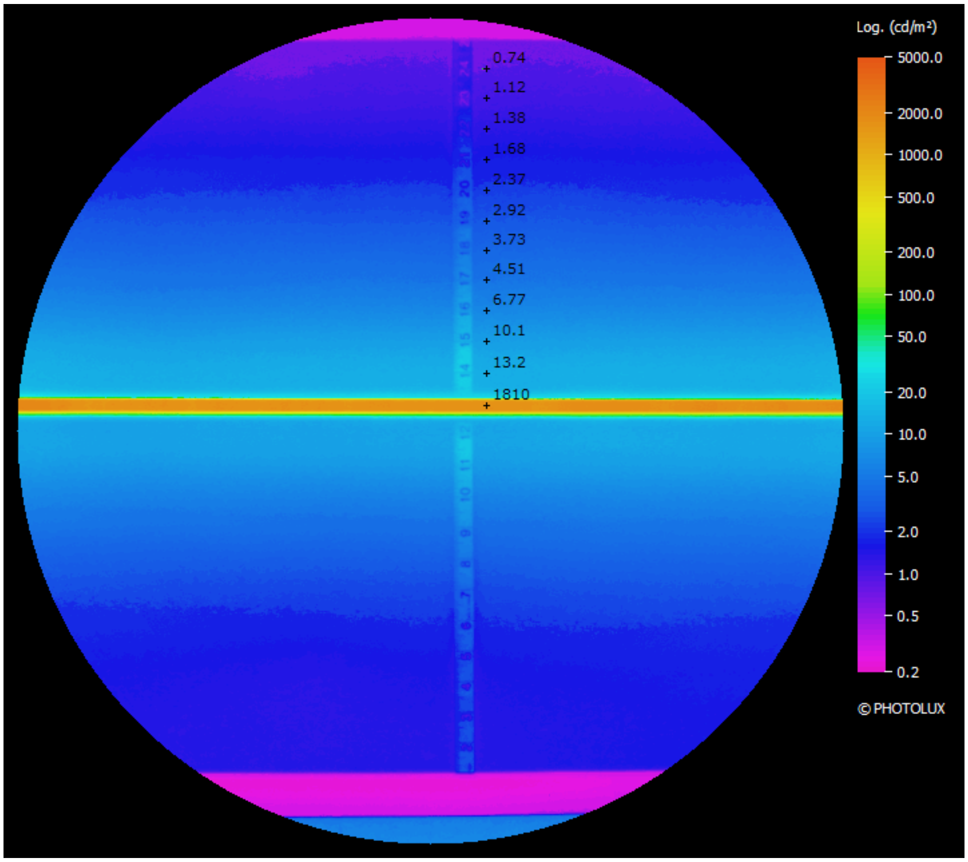




FIGURE 41. BLUE LED 3 LUMINANCE MAP AND GRAPH. THE LUMINANCE GRAPH IS OVERALL LOWER THAN NEON, BUT STILL RELATIVELY SMOOTH AND GRADUAL COMPARED TO LED 4, 5, AND 6, INDICATING LOWER CONTRAST AND MORE BACKGROUND ILLUMINATION.



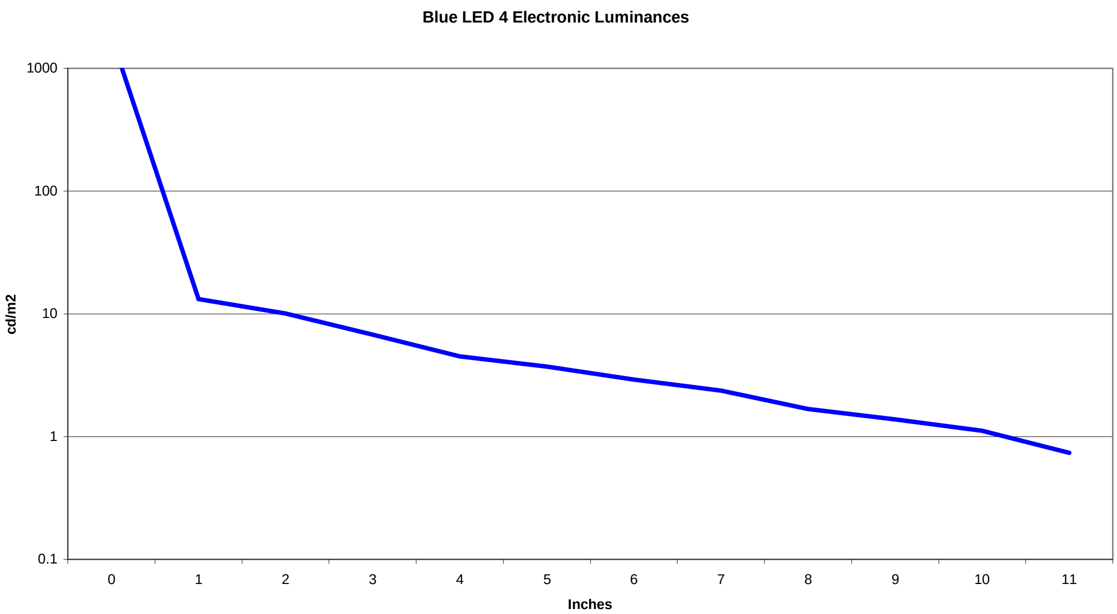
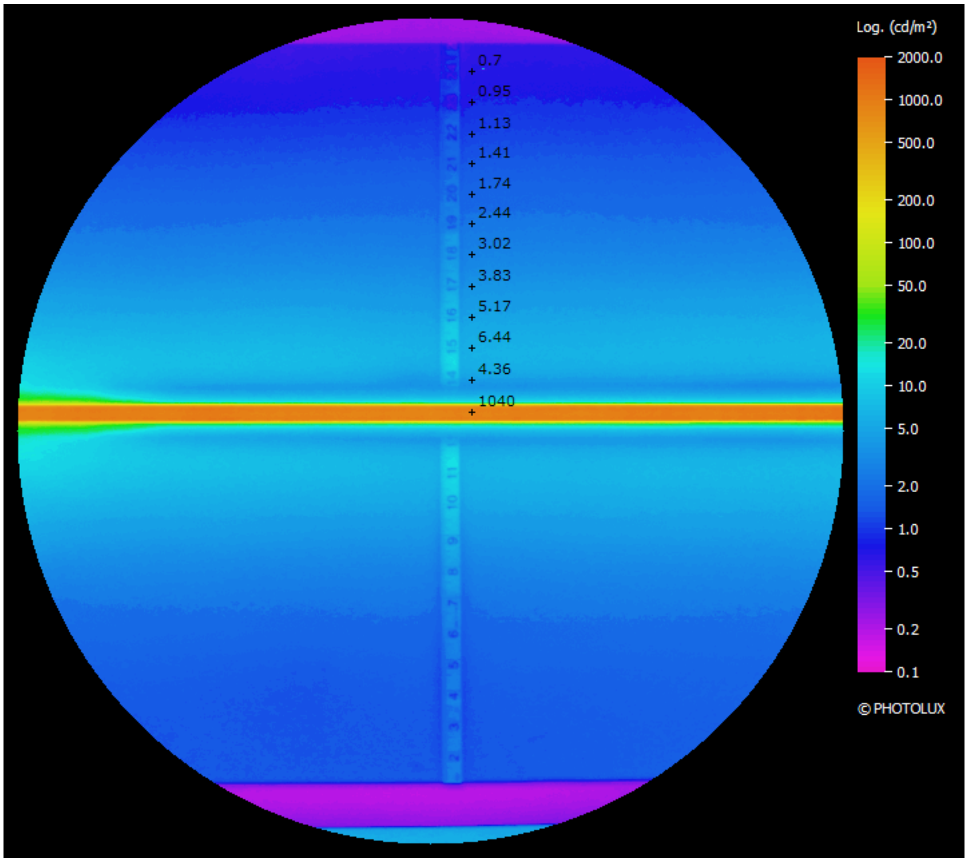




**FIGURE 42. BLUE LED 4 LUMINANCE MAP AND GRAPH. THE LUMINANCE GRAPH IS INITIALLY STEEPER THAN LED 3 AND 7, INDICATING HIGHER CONTRAST AND LESS INTENTIONAL BACKGROUND ILLUMINATION.**



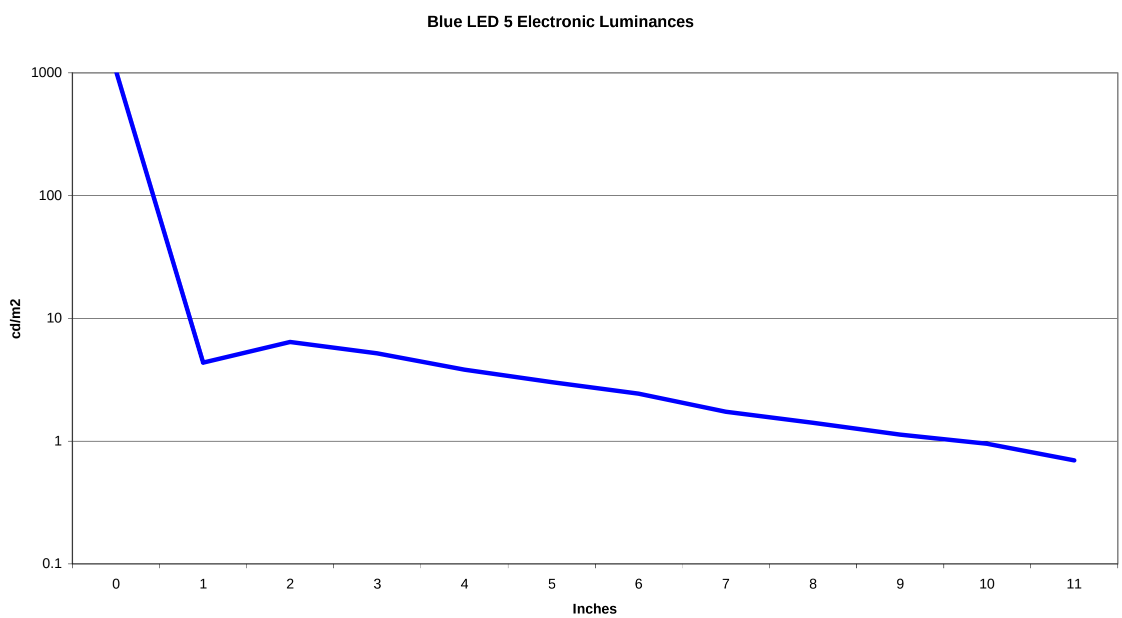
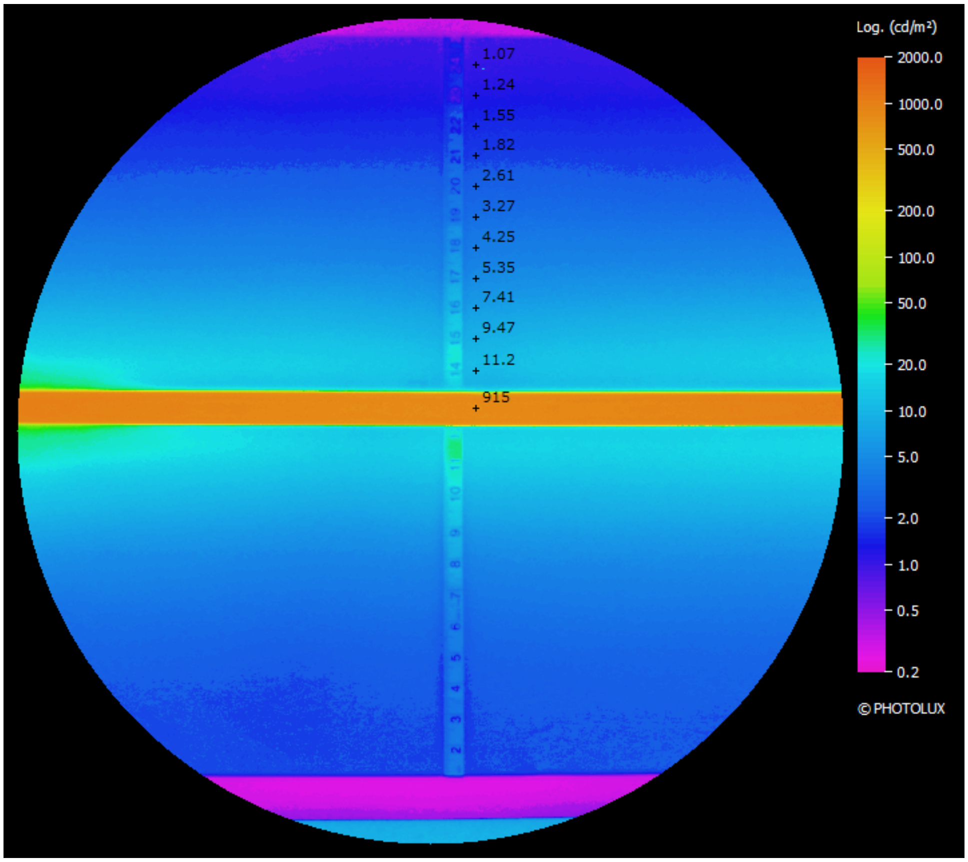




**FIGURE 43. BLUE LED 5 LUMINANCE MAP AND GRAPH. THE LUMINANCE GRAPH IS INITIALLY STEEPER THAN LED 3 AND 7, INDICATING HIGHER CONTRAST AND LESS INTENTIONAL BACKGROUND ILLUMINATION.**



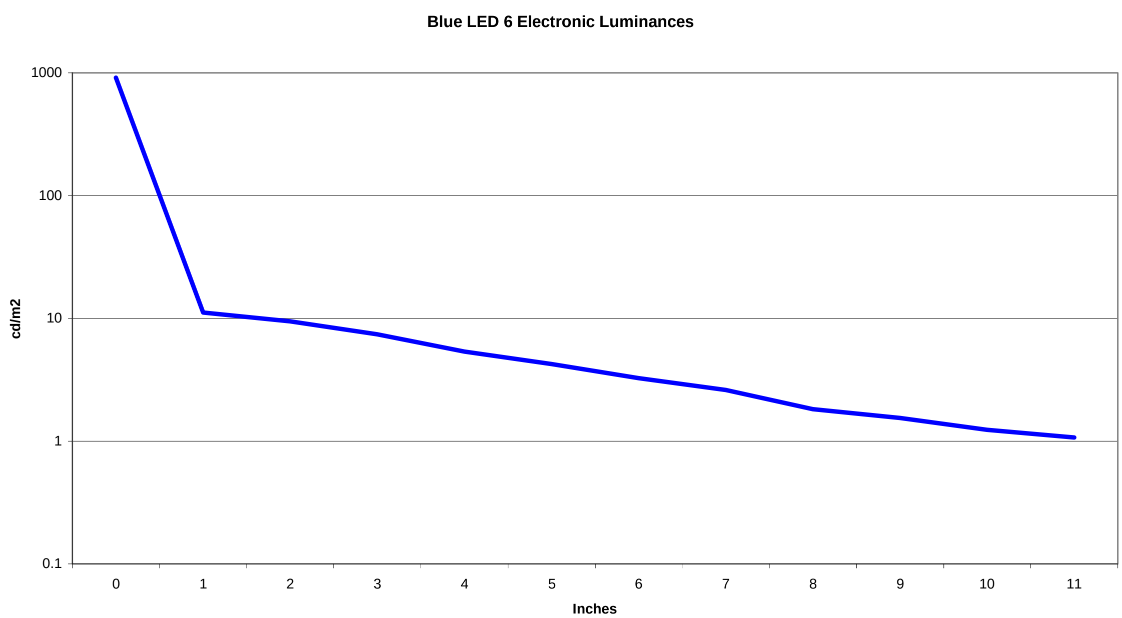
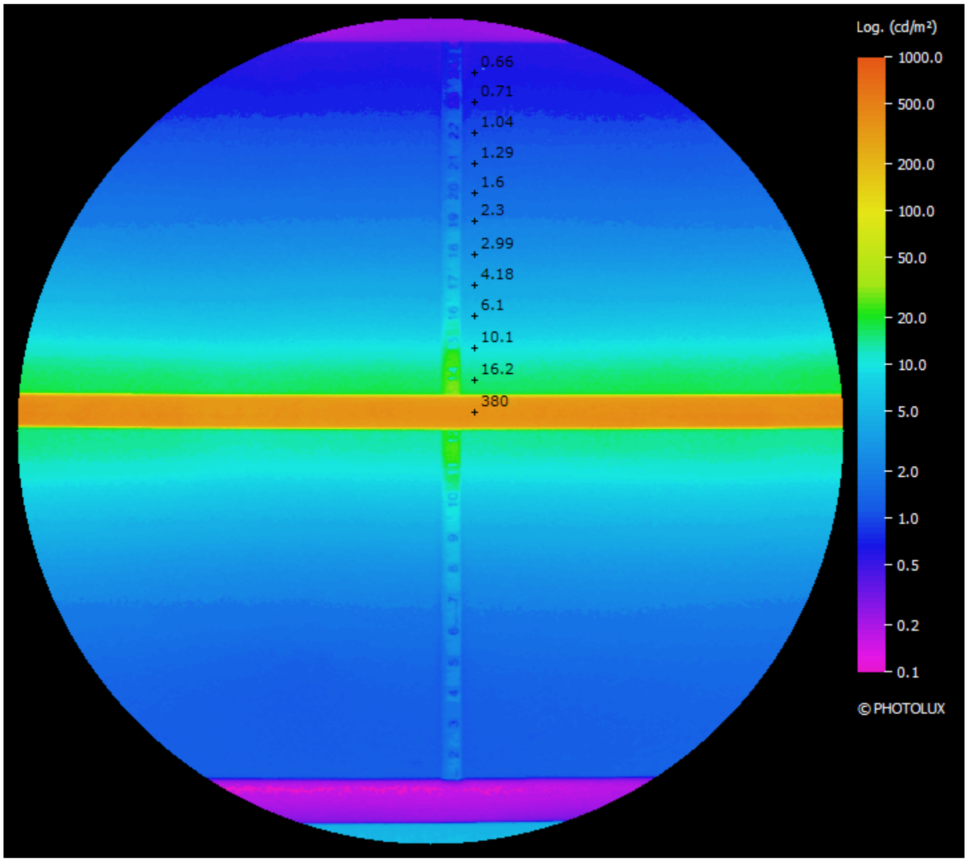




**FIGURE 44. BLUE LED 6 LUMINANCE MAP AND GRAPH. THE LUMINANCE GRAPH IS INITIALLY STEEPER THAN LED 3 AND 7, INDICATING HIGHER CONTRAST AND LESS INTENTIONAL BACKGROUND ILLUMINATION.**



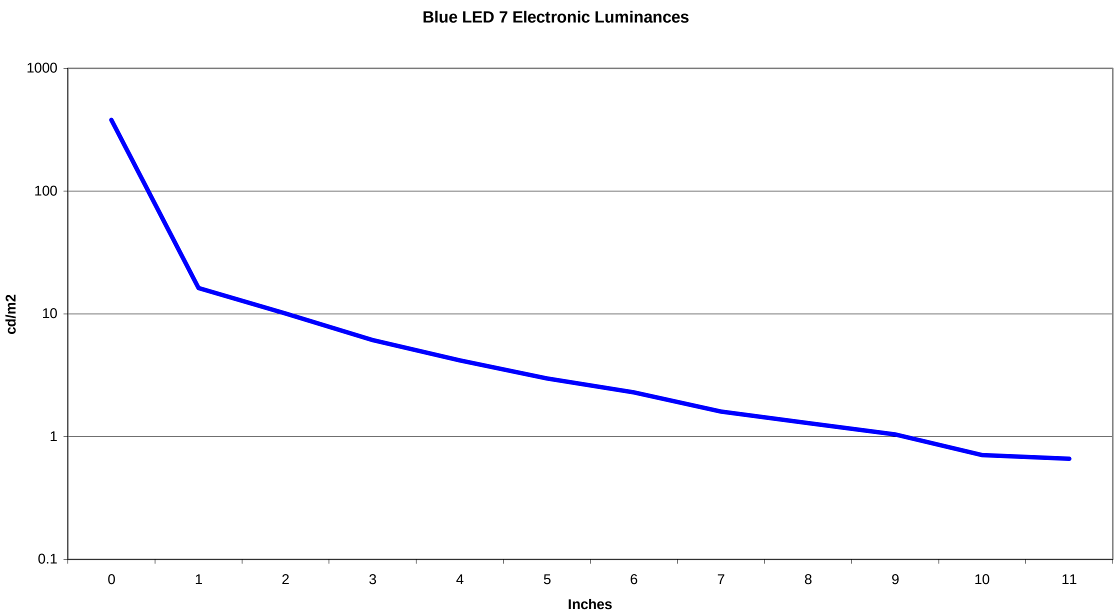




**FIGURE 45. BLUE LED 7 LUMINANCE MAP AND GRAPH. THE LUMINANCE GRAPH IS OVERALL LOWER THAN NEON, BUT STILL RELATIVELY SMOOTH AND GRADUAL COMPARED TO LED 4, 5, AND 6, INDICATING LOWER CONTRAST AND MORE BACKGROUND ILLUMINATION.**

From the luminance maps and graphs, neon creates a prominent halo effect by sending light in all directions, including illumination of the test sign cabinet behind the tube. While some of the LED products create this effect as well, some of them direct light in a narrower spread, sending it forward towards the camera and away from the cabinet. All colors follow the same trend as blue therefore the luminance maps for other colors are not shown.

# ENERGY SAVINGS

Assuming an ideal LED product that exhibits luminance, efficiency, color, and contrast similar to neon (a direct replacement, which is not the case with most LED colors and manufacturers), the energy savings was calculated by using Equation 4.

Annual energy savings is directly dependent on the products' annual operating hours. In some cases, operating hours may follow those of retail operating hours, especially in applications where the store is open overnight. In other cases, the products may be turned on for short periods around dusk and dawn, or left on overnight even when the store is closed. Assuming the products are on for 12 hours per day, 365 days per year, the energy savings is calculated as shown in Equation 4.

**EQUATION 4. ANNUAL ENERGY SAVINGS**

$$EnergySavings = (NeonAnnualEnergyUse) - (LEDAnnualEnergyUse)$$

**Where**

$$NeonAnnualEnergyUse = \frac{(NeonMeasuredPowerDensity) \times (Annual\ Hours)}{(1000W/kW)}$$

$$LEDAnnualEnergyUse = \frac{(LEDMeasuredPowerDensity) \times (Annual\ Hours)}{(1000W/kW)}$$

Equation 5 calculates the annual energy savings when using an average blue LED product at 3.0 W/ft instead of an average blue neon electronic product at 3.4 W/ft; this assumes that the LED is equivalent to the neon (which is not the case with most LED colors and manufacturers). The average annual energy savings for each color and technology is shown in Table 11.

**EQUATION 5. ANNUAL ENERGY SAVINGS FOR AVERAGE BLUE LED PRODUCT**

$$1.752kWh/ft = (14.892kWh) - (13.14kWh)$$

**Where**

$$14.892kWh/ft = \frac{(3.4W/ft) \times (4380)}{(1000W/kW)}$$

$$13.14kWh/ft = \frac{(3.0W/ft) \times (4380h)}{(1000W/kW)}$$

**TABLE 11. ANNUAL ENERGY SAVINGS - ASSUMING THAT LED PRODUCTS ARE EQUIVALENT TO NEON**

| Color | Neon Electronic W / | Neon Magnetic W / | LED W / | kWh / Savings Over Neon Electronic | kWh / Savings Over Neon Magnetic |
|---|---|---|---|---|---|
| Blue | 3.4 | 3.9 | 3.0 | 1.752 | 3.942 |
| Green | 3.4 | 3.9 | 3.0 | 1.752 | 3.942 |
| Orange | 3.5 | 3.9 | 2.7 | 3.504 | 5.256 |
| Red | 3.5 | 3.9 | 2.8 | 3.066 | 4.818 |
| White | 3.3 | 3.8 | 2.9 | 1.752 | 3.942 |
| Yellow | 3.4 | 3.9 | 2.7 | 3.066 | 5.256 |

Since no data is available on the expected lifetime of linear LED products, lifetime energy savings are not calculated.